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The International Conference on Sustainable Futures:

Environmental, Technological, Social and Economic Matters

May 20-22, 2020

Kryvyi Rih, Ukraine

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Title, date and place of the conference

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Our sustainable coronavirus future

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Abstract. This is an introductory text to a collection of papers from the ICSF 2020: The International Conference on Sustainable Futures: Environmental, Technological, Social, and Economic Matters, which held at Kryvyi Rih National University, Kryvyi Rih, Ukraine, on May 20-22, 2020. It consists of an introduction, conference topics review, and some observations about the event and its future.

ICSF 2020 at a glance

The International Conference on Sustainable Futures: Environmental, Technological, Social and Economic Matters (ICSF) is a peer-reviewed international conference, which is the premier interdisciplinary forum for social scientists, life scientists, engineers, and practitioners to present their latest research results, ideas, developments, and applications (Fig. 1).

Fig. 1. ICSF 2020 logo (designed by Dr. Andrii Striuk).

The ICSF occupies contributions in all aspects of sustainable development, focused on the intersection of sustainability, environment and technology, and their more significant implications for a corporation, government, education institutions, regions, and society both at present and in the future.

ICSF has two presentation levels, Pre-conference Workshops and Main Conference.

Ecochemistry Education for Sustainable Development Workshop

Ecochemistry Education for Sustainable Development Workshop (EcoChemSD-WS'2020) is a peer-reviewed international workshop that occupies contributions in all aspects of environmental chemistry and ecochemistry, ecochemistry education, and modern educational technologies.

EcoChemSD-WS'2020 main topics of interest are:
- ecochemistry research for the sustainable development;
- environmental chemistry for the sustainable development;
- ecochemistry education for the sustainable development;
- modern educational technologies in the chemistry education;
- chemistry teacher's training for the sustainable future.

EcoChemSD-WS'2020 Program Committee chair is Dr. Pavlo Nechypurenko.

Fintech, Greener Economy & Finance Workshop

Science has confirmed that the world is facing an environmental emergency. As it stands, very few countries are on track to meet either their national climate targets or reach the Sustainable Development Goals. It is now clear that we need a radically different approach to governing our economies. A green economy defined as low carbon, resource-efficient, and socially inclusive. In a green economy, growth in employment and income is

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driven by public and private investment into such economic activities, infrastructure, and assets that allow reduced carbon emissions and pollution, enhanced energy and resource efficiency, and prevention of the loss of biodiversity and ecosystem services. New financial technologies ("fintech") offer the potential to unlock green finance technologies, such as blockchain, the Internet of Things, and Big Data assisting in the transition to a greener economy. By reducing costs and boosting efficiency, fintech mobilizes green finance, enables poorer people to access clean energy through innovative payment systems, and facilitate free savings for rich and poor alike.

The financial markets and the promotion of sustainable finance play a crucial role in mitigating climate change. The topic will address in the Fintech, Greener Economy & Finance Workshop (FGE&F-WS'2020), which aims to provide a forum for different perspectives and ideas to stimulate the debate around sustainable future.

FGE&F-WS'2020 main topics of interest are:
- challenges of the green economy concept and policies in the context of sustainable development, poverty and equity;
- potential opportunities and risks of trade, arising in the transition to the green economy;
- impact of climate change on financial markets, and vice versa;
- means by which financial markets can support sustainable finance;
- significance of digitalisation, financial technology and data for green investments;
- challenges in defining sustainability;
- role of climate change in financial supervision and financial risks;
- blockchain applications for sustainable development;
- blockchain use-cases for renewable energy, decentralized electricity market, carbon credits and climate finance;
- innovation in financial instruments, including green bonds;
- fintech and risks and dangers;
- recommendations to design a sustainable financial and economical system.

FGE&F-WS'2020 Program Committee chairs are Prof. Vladimir Soloviev and Dr. Victoria Solovieva.

Geography Education for Sustainable Development Workshop

Geography Education for Sustainable Development Workshop (GESD-WS'2020) is a peer-reviewed international workshop. During the GESD-WS'2020, the researchers who are committed to the problems of geographic education for sustainable development can present their latest research findings, ideas, developments, and programs.

GESD-WS'2020 main topics of interest are:
- geography education for the sustainable future: methodological foundations;
- pedagogical geoinformation technology: theory and practice;
- geography teacher's training for the sustainable future;
- innovative technologies in the school geographic education;
- cartographic territory research in terms of the sustainable future.

GESD-WS'2020 Program Committee chair is Dr. Olga Bondarenko.

Green IT Hub Workshop

Green IT Hub Workshop (GITHub-WS'2020) is a peer-reviewed international Sustainable Computing workshop focusing on advanced research on Sustainable Computing. The workshop occupies contributions in all aspects of sustainable computing, reflecting modern engineering and technological solutions of the information technology era in the sustainable development of society.

GITHub-WS'2020 main topics of interest are:
- sustainable computing;
- software development for a sustainable society;
- information systems and technologies in the society sustainable development;
- cloud technologies and IoT in the society sustainable development.

GITHub-WS'2020 Program Committee chair is Prof. Tetiana Vakaliuk.

ICT in Education and Sustainable Futures Workshop

ICT in Education and Sustainable Futures Workshop (ICT@ESF-WS'2020) is a peer-reviewed international workshop focusing on the efficient application of information and communication technologies in education, research, economics, ecology, and medicine for a sustainable future.

Contributions in all aspects of the sustainable use of ICT in education and science, reflecting modern solutions for the use of ICT in the sustainable development of society, can be submitted. Today, the most important goal is the ability to integrate the efficient application of ICTs in education, update the pedagogical science, and change education for a sustainable future most fully. It is necessary to give educators and researchers the opportunity to better understand the transformation of society through the use of ICT; to promote the development of new educational approaches and the creation of new educational materials using ICT in support of a sustainable future and "new humanism"; to support the exchange of experience and cooperation between teachers, lecturers and researchers in the dissemination of innovative practices in the use of ICT in education and research within the international educational community. It is vital to present the effective application of ICT in reinforcing the four foundations of learning in the 21st century: critical thinking, communication, collaboration, and creativity.

ICT@ESF-WS'2020 main topics of interest are:
- ICT in secondary education for a sustainable future society;

- ICT in higher education for a sustainable future society;
- ICT in research for a sustainable future;
- supporting the development of 21st century skills through ICT;
- integration of ICT into the economy of a sustainable development society;
- ICT in solving environmental problems of sustainable development.

ICT@ESF-WS'2020 Program Committee chair is Prof. Viacheslav Osadchyi.

Main Conference

Main Conference presentations are grouped into 13 tracks:

1. Sustainable Environment and Environmental Management [1-13].
2. Geotechnical and Geoenvironmental Engineering [14-23].
3. Sustainable Mining [24-31].
4. Sustainable Energy [32-38].
5. Sustainable Computing [39-45].
6. Sustainable Materials and Technologies [46-57].
7. Sustainable Transport [58-62].
8. Sustainable Building and Architecture [63, 64].
9. Sustainable Cities and Society [65-69].
10. Sustainable Education [70-105].
11. Measuring, Forecasting and Monitoring Sustainability [106-108].
12. Corporate Sustainability and Corporate Social Responsibility [109, 110].
13. Sustainable Economy [111-141].

This volume contains the papers presented at ICSF 2020: The International Conference on Sustainable Futures: Environmental, Technological, Social, and Economic Matters held on May 20-22, 2020 in Kryvyi Rih, Ukraine.

There were 285 submissions. Each submission was reviewed by at least 3, and on the average 3.5, program committee members. The committee decided to accept 141 papers.

ICSF 2020 venue

Kryvyi Rih National University has almost 100-year experience in training generations of specialists (Fig. 2). It is one of the most prestigious higher educational institutions in Ukraine as well as the powerful regional center of Higher Education, science and culture.

Over 100 thousand students from 70 countries all over the world have trained in the university. Currently, the friendly university family includes more than eleven and a half thousand young people getting an education in over forty majors in full and part-time modes of study. Fruitful cooperation with partner universities abroad and integration of the participatory research results in the teaching process facilitate the university's internationally competitive level of education. The university scientists carry out a significant amount of research and design studies in the most urgent evolution directions and tendencies of industrial and social branches in Ukraine and other countries.

The mission of Kryvyi Rih National University is to contribute to the development of society employing competitive specialists training as well as inspiring a new generation of healthy and creative patriotic youth. Guiding principles for sustainable university development are multiplying achievements in science, education, culture, and continuing the proud traditions fostered by dynasties of scientists, professors and researchers. The constant development of the university makes sustainable ground for its promising prospects [142].

Fig. 2. Kryvyi Rih National University main building.

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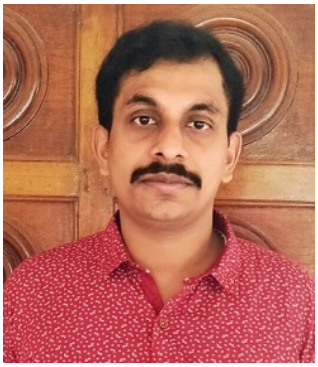

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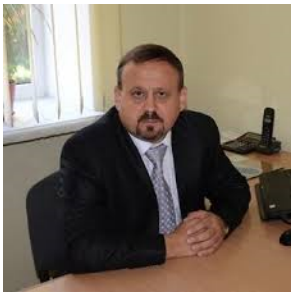

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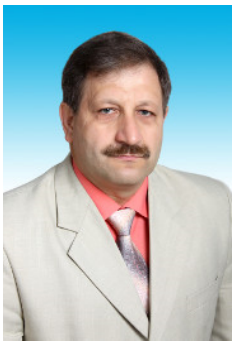

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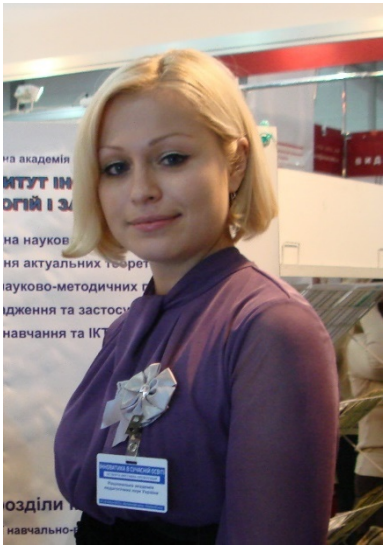

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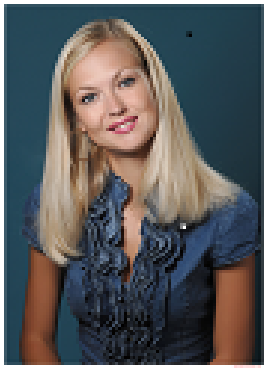

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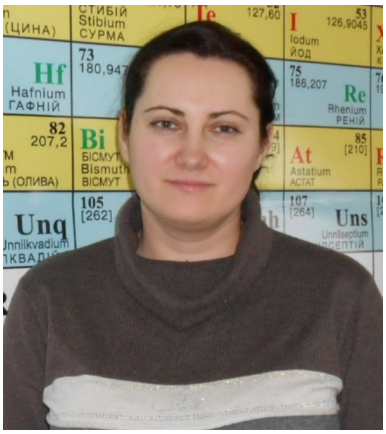

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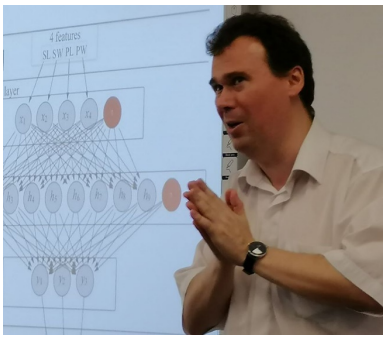

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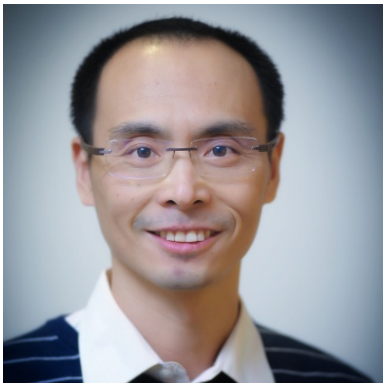

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How coronavirus is shaping sustainable development

"The world is changed. I feel it in the water. I feel it in the earth. I smell it in the air. Much that once was is lost, for none now live who remember it." [143]

The rapid spread of the coronavirus that causes COVID-19 has change conference organization. In Ukraine, the Ministry of Healthcare is advising people to prepared for disruptions to daily life that will be necessary if the coronavirus spreads within communities. On March 11, 2020, the Cabinet of Ministers of Ukraine introduced a three-week nationwide quarantine in connection with a pandemic, and all public events in the country have been canceled [144]. Three weeks ago, we still believed that the outbreak impact would not be global [145].

"Conferencing world from the past now seems surreal, like science fiction, though the world around us looks like science fiction too" [146]. As the conference organizers, in the current crisis we had to make a rational decision regarding the paper presentations: a) cancel this year conference and put presentations online; b) postpone the conference to an indefinite time in the vague future; c) change dates to Fall 2020; d) merge conferences of this and next year; e) allow the mixed participation, both real and virtual.

It seems the last choice is safe and rational, so we decided not to change ICSF dates and give to participants the possibility to make a real presentation using ICT augmentation.

The coronavirus pandemic is now affecting practically every country on the planet. The quarantine restrictions put in place by the governments have a lot of serious socio-economic, technological and environmental effects. Could the coronavirus outbreak be sustainability's big break?

Peter Bakker, the President of World Business Council for Sustainable Development (WBCSD), emphasis that most governments are now first and foremost focused on slowing down the spreading of the disease and shoring up medical support systems to aid those who fall seriously ill: "For business, it is an equally pivotal moment to deploy all its care, critical know-how, reach and resources. Businesses everywhere are looking after their employees and creating contingency plans to map the risks in their operations" [147]. The WBCSD has started sharing examples of positive business leadership during these challenging times: how business demonstrating their responsibility towards society.

WBCSD has set up a COVID-19 Response Program. WBCSD's call to action to leverage our combined business expertise centered on three areas and focused projects:
- Vital Supply Chains (with a focus on short-term supply chain resilience plan, starting with the food system);
- Return to "Normal" Scenarios (with a focus on employee health and business recovery);
- Long-term Impacts (with a focus on COVID-19 vulnerabilities revealed by the crisis and lessons for future resilience and stakeholder capitalism).

Kevin Moss mentioned that COVID-19 crisis could be a turning point for business: "Right now, businesses are responding to the call to take a socially responsible, purpose-driven and publicly accountable approach to all stakeholders – employees, suppliers and communities – in addition to shareholders. It may seem inappropriate to be thinking of longer-term sustainability in these times of emergency, but the lens through which we are forced to take urgent action right now is the one business leaders can use to ensure the rush to resolve one emergency does not accelerate the onset of another. Let this be the beginning, not the peak, of a corporate transformation journey, so that once society is beyond the immediate threats, we move into a refreshed approach to capitalism" [148].

This crisis offers three opportunities for businesses that want to expand their mandates to lead to a more sustainable future [148]:

1. *Change business models from a linear to a circular economy*: instead of coming out of the crisis by doubling down on pre-crisis consumption patterns and business models, the crisis presents the opportunity to switch from selling more stuff to more people to providing services, reselling previously owned products and creating.

2. *Emphasize the social in the environmental, social and corporate governance*: if ever there was a time for companies to demonstrate their commitment to the health, safety and prosperity of all stakeholders by addressing inequality in the business model, it is now.

3. *Invest in supply chains*: as the Science Based Targets Network notes in its call to action for companies, businesses must prioritize mapping "value chain and assess the risk to freshwater, biodiversity, ecosystems and oceans in major impact locations" [149].

So, COVID-19 has tested the preparedness and resiliency of businesses in terms of their ability to respond to a systemic global shock. Some business responses to the current situation highlight future corporate sustainability opportunities [150].

The UN Secretary-General António Guterres has announced the establishment of the COVID-19 Response and Recovery Fund and launched a report serving as a call to action [151]. Guterres said the recovery from the COVID-19 crisis must "lead to a different economy" – more equal, inclusive and sustainable, to be more resilient to pandemics, climate change, and other global challenges.

The Fund has three aims, with a finance window for each one: stop transmission of the virus, protect the most vulnerable from its socio-economic impacts, and make countries more resilient to future health crises. Window 1, "Enable governments and communities to tackle the emergency", will support countries to fully implement their National Action Plans for Health Security, helping them close gaps in acquiring essential equipment and supplies, and pay health and social workers.

Window 2, "Reduce social impact and promote economic response", will support immediate social protection measures including cash transfers and food security. It will enable school meal programs and learning to meet children's food and educational needs while boosting digital innovations to support employment, livelihoods, and social services.

Window 3, "Recover better", focuses on national preparedness measures such as maintenance of key services and workforces during crises, and laboratory capacity. This window will also invest in innovative delivery of public services to "achieve sustainable and inclusive economies that leave no-one behind and safeguard country SDG programs from COVID-19-related setbacks".

The UN report on social and economic impacts of the virus outbreak entitled "Shared responsibility, global solidarity: Responding to the socio-economic impacts of COVID-19" [152] is a call to action for the same sets of action prioritized by the Fund. Guterres highlighted the importance of focusing on the people most affected socially and economically by the pandemic: women, older persons, youth, low-wage workers, small and medium enterprises, the informal sector, and vulnerable groups, especially those in humanitarian and conflict settings. He said a multilateral response of about 10% of global GDP will be needed, and that we must prioritize debt alleviation.

Looking longer-term, Guterres said, "when we get past this crisis … we will face a choice. We can go back to the world as it was before or deal decisively with those issues that make us all unnecessarily vulnerable to crises".

Pointing to the 2030 Agenda and its 17 Sustainable Development Goals (SDGs) as "our roadmap," he said the recovery from the COVID-19 crisis must "lead to a different economy" – more equal, inclusive and sustainable, to be more resilient to pandemics, climate change, and other global challenges.

The COVID-19 Response and Recovery Fund and Call to Action report take a long-term view, stressing that the world must address the issues that "make us all unnecessarily vulnerable to crises", with the 2030 Agenda serving as the roadmap to achieving this (Fig. 3). The Fund seeks to stop transmission of the virus, protect the most vulnerable from its socio-economic impacts, and make countries more resilient to future health crises.

The United Nations commits to working in all countries around the following recommendations [152]:

1. Act decisively and early to prevent the further spread or quickly suppress the transmission of COVID-19 and save lives.

2. Urgently strengthen the resilience of health systems.

3. Provide urgent support to developing countries with weaker health systems.

4. Remove obstacles and allow free and immediate access to research results and ensure that vaccines and

medicines are accessible to all.

5. The United Nations calls on all businesses and corporations to take three primary actions: adhere to health, safety guidelines and provide economic cushions to workers, including through ensuring worker safety and social distancing and secure wages for those working from home; provide financial and technical support to governments by contributing to the COVID-19 Solidarity Response Fund; repurpose their facilities and business plans to focus on meeting the needs of this crisis.

Fig. 3. COVID-19 affecting all 17 SDGs [152, p. 12].

Conclusion

The vision of the ICSF 2020 is to create a leading interdisciplinary platform for researchers, practitioners and educators, to present and discuss the most recent innovations, trends, and concerns as well as practical challenges encountered and solutions adopted in the fields of sustainability.

The conference is a successfully performing forum for transferring and discussing research results among the academics, students, teachers, government, private sector, or industries. Participants and presenters from several countries such as Australia, Azerbaijan, Belarus, Bulgaria, Czechia, Egypt, Estonia, Georgia, Germany, Guinea, Indonesia, India, Israel, Italy, Kazakhstan, Kuwait, Lithuania, Netherlands, Nigeria, Norway, Poland, Romania, Russia, Saudi Arabia, Serbia, Sweden, Turkey, Ukraine, United Kingdom, United States, Uzbekistan, and Viet Nam have a conference experience to share their significant contribution in the research of the environmental, technological, social and economic issues of sustainable future.

We are thankful to all the authors who submitted papers and the delegates for their participation and their interest in ICSF as a platform to share their ideas and innovation. Also, we are also thankful to all the program committee members for providing continuous guidance and efforts taken by peer reviewers contributed to improving the quality of papers provided constructive critical comments, improvements and corrections to the authors are gratefully appreciated for their contribution to the success of the conference. Moreover, we would like to thank the developers and other professional staff of EasyChair, who made it possible for us to use the resources of this excellent and comprehensive conference management system, from the call of papers and inviting reviewers, to handling paper submissions, communicating with the authors, and creating the conference proceedings.

We are looking forward to excellent presentations and fruitful discussions, which will broaden our professional horizons. We hope all participants enjoy this conference and meet again in more friendly, hilarious, and happiness of further ICSF 2021.

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Software tools for tasks of sustainable development of environmental problems: peculiarities of programming and implementation in the specialists' preparation

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Abstract. It is necessary to follow signed documents on development of renewable energy, modernization of fuel and energy sector enterprises and waste management in order to fulfil Ukraine's commitments to the global community on climate change prevention. Therefore, it is an urgent task to develop software that allows to solve problems of visual analysis of environmental status dynamics of territorial systems and to determine boundaries of individual territories stability. The authors propose new forms of monitoring data presentation of technogenic loadings and risks which reflect dynamics of environmental situation in the space of informative features. It is important to improve skills of professionals, particularly, stuff of the ministries, enterprises and organizations responsible for decision-making to reduce negative impact on environment and to train future professionals in this area. Curriculums of higher education institutions do not pay much attention on usage of software to support managerial decision-making to reduce negative impact on the environment. It is proposed to improve qualification of such specialists, responsible for management in the following areas: conducting training seminars at the ministries, institutions and departments interested in the implementation of developed systems; scientific and methodological support and advisory assistance in the process of implementation of the software; development and improvement of educational and methodological support for postgraduate students and trainees of advanced training, specialists responsible for decision - making in energy, environmental and related fields.

1 Introduction

A report of the World Commission on Environment and Development "Our Common Future" defines sustainable development as "development that meets needs of modern times without sacrificing future generations to meet their own needs" [1]. From an environmental point of view sustainable development must ensure integrity and viability of natural systems, possibility of self-healing and adaptation to change. In particular, the study of the relationship between environmental and economic components of sustainable development processes requires clarification of limit levels of technogenic loads and to determine the stability limits of urban territorial systems to technogenic impacts.

At this stage, approaches to sustainable development research can be divided into two directions. The first direction is dominant at the global and regional level (top view, i.e. comparative analysis of situation in different countries or regions). These studies aimed to calculate sustainable development indicators and indices according to the methods proposed by the UN Commission and international councils [2-5]. The next one should include work aimed to identify the stability of individual processes occurring in specific environmental or social systems [6-8]. Only real examples of dynamics analysis of individual systems can reveal dependence on trajectory development (or transition to critical state) of this system on values of the mentioned or other parameters.

Special attention should be given to the development and modernization of monitoring system of ecological status of territorial systems at different levels; to create universal information and monitoring software for monitoring tasks, improving tools of forecasting critical situations and to make necessary management decisions. It should be done for practical implementation of the principles of sustainable development in Ukraine. Development of modern information and computer technologies are focused on the storage, accumulation, systematization and integration of information obtained from various sources, including local level of data analysis and visual interpretation capabilities based on GIS technologies are among the top priorities that is evidenced by the accepted concept [9]. Its implementation should ensure compliance with

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international commitments in the field of environmental protection, rational use, renewal and protection of natural resources.

Therefore, we consider two aspects important for the research: improvement of monitoring system to forecast and managerial tasks to ensure environmental safety based on information technologies; professional development of specialists in the energy, environmental and related fields who are responsible for decision-making to reduce negative impact on environment.

2 Analysis of previous publications

Most publications on sustainable development have the following scholars: M. Zghurovs'kyj, P. Priyadarshini, H. Fredrickson, L. Zhao, S. González-García, J. Baleta, M.-H. Yuan, S.-L. Lo, A. Dawodu, A. Cheshmehzangi. Was made systematization of scientific publications in the following areas directly related to this research based on analysis of the works of foreign and domestic scientists:

- approaches to sustainable development [4, 6, 8, 10-13];
- development of indicators, indices to measure sustainable development [2, 14-21];
- construction of mathematical, software and hardware tools to assess impact of potentially dangerous enterprises on environment, taking into account economic indicators [22-33];
- training of specialists in the field of environmental safety and related industries [34-46].

However, further research should be dedicated to the questions of comprehensive and predictive assessments of environmental situation in technogenic territories in the context of sustainable development and skills development for professionals working in the energetic, environmental and related fields.

Aim: is to describe features of software application for sustainable development tasks and to outline directions of professional development of specialists responsible for management decisions in the energy, environmental and related fields.

3 The research results

3.1 Energy industry: from environmental security to sustainable development

One of the environmental safety assessing criteria of particular ecosystem is quality of life and health of population. There is need for purposeful impact (management) of ecological system in order to improve its organization and to achieve some beneficial effect.

Sustainable development models to measure system efficiency consist of economic, environmental and social subsystem were proposed in the research [10]. The result of the study is illustrated in 30 major Chinese cities. It shows main factors that affect their economic, environmental and social performance.

There is a need in planning and in policies that will be able to promote sustainable growth in order to conserve resources and guarantee social services and the well-being of citizens. Socio-economic analysis is essential for establishing a comprehensive diagnosis of the resilience of urban and rural systems in addition to environmental perspective. The work [11] presents methodology to assess sustainability based on 38 indicators that include three bases of sustainability: social, economic and environmental. This methodology was tested in many municipalities in north-western Spain. The research results showed that the most resilient municipalities are located in the north of the region. Size of municipalities is important to measure stability. The publication authors noted that developed methodology is reliable and can be applied to other municipalities and cities.

Joint efforts and a multidisciplinary approach are needed to address global warming. Circular economics together with resource efficiency is focus of researchers and politicians. Sustainable development is a multidisciplinary topic. Interaction of energy, water and environment plays central role. In circular economy paradigm there is growing need for system integration when by-product of one system can represent resource for another. The research [12] highlighted issues of sustainable development of energy, water and environment systems. It was emphasized that more efforts should be made to further integration of these systems. All listed above leads to increase in complexity of such problem. It can be only solved by collaboration of many scientists from different fields of research.

Integration of energy, water and environment systems is important in the multidisciplinary concept of sustainable development as they represent basic necessities of humanity. Therefore, problems arising from the concept of sustainable development should be carefully addressed to conserve energy, water and environmental resources for future generations. Some recent developments in these major areas of sustainable development are discussed in [13].

3.2 Problem statement for sustainable monitoring for territories development

Environmental monitoring includes system of observations on factors that affect environment, process for assessing of the environment actual state, estimation, certain control and management capabilities. Environmental indicators are considered as separate indicators with significant impact on status of studied areas. Environmental indexes are considered as complex indicators.

Structural approach to assess the state of individual territories is developed for problems of impact analysis and technogenic impact. It is substantiated to determine indicators of environmental status (integral indices) based on data of urbanized territories monitoring in work [20]. Three types of environmental indicators are proposed to identify indicators of the urban areas environmental status:

1) the most informative among indicators recorded as result of measurements at the posts (concentrations of

the most dangerous substances);

2) multidimensional indices of ecological status of studied territories, based on set of measured indicators;

3) environmental risk estimation (probability distributions or risk fields) calculated on the basis of monitoring data.

Generalized estimations (indicators) of ecological status of these territories are determined on the basis of ecological monitoring data of the studied territories under conditions of high technogenic loads.

Site planning, construction and deployment of industrial facilities, land and natural resource management, vehicle management, agricultural development, accident or emergency simulation are typical sustainable development tasks that require the use of spatial analysis tools and technologies [2].

There are following tasks of monitoring, analyzing and evaluation of sustainable development of regions and individual territories: identification of spatial structure of systems under study (distribution of technogenic loads, distribution of risks and diseases, identification of dangerous zones); analysis of certain changes and determination of main trends for studied period (monitoring of dynamics of technogenic loads); predicting of possible scenarios for typical situations (in particular, assessing of potential impact of dangerous factors and effectiveness of management decisions).

One of priority tasks for assessment and modeling of sustainable development processes at territorial level is to determine stability limits of studied territorial systems under pressure of high technogenic loads.

Natural boundaries of sustainability in the concept of sustainable development determine state of biosphere and society which will preserve our civilization and basic natural resources for future generations. Therefore, it is necessary to determine such maximum permissible levels of load on separate territorial systems for which stable state can still be ensured [47].

Let's remember the definition of stability by Lyapunov in order to clarify the concept of the stability of dynamic systems. Trajectory of dynamic system can be considered stable if for any number of small deviations (that determine limits of stability of this system) such constraints can be specified for possible vibrations at which the system does not go beyond certain limits [48].

There are main stages of territorial systems research in order to determine stability limits to impact of technogenic loads.

1. Spatial analysis of man-made pollution monitoring data and identification of high-risk areas. In preliminary stages of analyzing monitoring data it is necessary to determine informative parameters (or environmental indexes) that are used to rank the sites and build environmental scales.

2. Results visualization of spatial analysis in the form of two-dimensional semantic scales, i.e. informative projections of semantic space of risks. It provides assessment and ranking of the studied territories by the indices of ecological status.

3. Visual analysis of technogenic loads dynamics over period of time in high-risk zones (maximum voltage points) using stability scales and visual determination of the stability limits.

3.3 Analysis of tools and results

The authors of this publication developed an analytical and information system to monitor the technogenic environmental loads in order to study the spatial-distributed tasks of anthropogenic impact analysis on territorial systems. This monitoring system provides possibility to analyse complex processes and phenomena that reflect monitoring data of individual cities, regions or territorial systems. This software consists of several blocks, namely: block of statistical analysis and preliminary estimation of technogenic atmospheric loads; mathematical modeling and forecasting unit of atmospheric pollution and risks for the population; block of visualization and construction of ecological maps [26].

This system can be used as auxiliary tool for informational support of environmental monitoring tasks, monitoring of pollution from potentially dangerous objects, ecological safety management in conditions of technogenic pollution of atmosphere surface layer. It is necessary to support decision-making on ensuring civil protection of population and territories with increased technogenic loads. Developed software can provide local governments and other stakeholders with valuable information that is necessary to make the most effective decisions based on local outcomes.

Fig. 1 shows block diagram of software to manage environmental safety of urban areas. It includes tool to model and forecast technogenic environmental loads (in particular, atmospheric air) from stationary sources of pollution.

Methodological analysis of sustainable development processes requires determination of stability criteria of studied territorial systems. It needs to be known in order to calculate the restrictions on technogenic loads.

Task of defining such criteria can be seen as inverted to task of monitoring of technogenic loads at local level, i.e. task of those boundaries clarifying which can lead to catastrophic changes in systems under study.

Special attention should be paid to the development of tools for visual analysis of monitoring data and technologies for the construction of ecological scales among methodological tools aimed at determining the boundaries of urban areas sustainability. It provides visual reflection of changes dynamics in ecological status of territorial system over researched period.

Let's consider some of the graphical visualizations of processes under research based on computer-based visual observation of approaching boundary conditions process. It is necessary to take into account monitoring data and regulatory data on restrictions on maximum permissible concentrations and risks.

The proposed tool to change dynamics in ecological status analyzing and to determine the stability of urban areas boundaries to technogenic impact were tested on the example of the territorial system of Kyiv, Ukraine. The research was conducted using the city's atmospheric

air monitoring data from the Sreznevsky Central Geophysical Observatory from 2005 to 2018 [49].

In the previous stages of analysis, the most informative indicators of pollution were identified to monitor the dynamics of technogenic loads on the city. They have high danger class, large range of seasonal fluctuations and significantly exceed limits established by the current legislation. Dynamics peculiarities of technogenic influence on the surface layer of air were investigated on the examples of such dangerous substances – pollutants such as formaldehyde, nitrogen dioxide and carbon monoxide.

Values of risks for the population of different districts of Kyiv were determined based on the monitoring data. Chronic intoxication risk (RCI) and risk of immediate toxic effects (RITE) were calculated using the formulas described in [50]. Dynamics of health risks can be monitored at specific points in the city according to these data. Estimates of risks for population for the study period are given in Table 1. Fig. 2 shows examples of risk maps due to air pollution in Kyiv, January-December 2017.

According to the given above data the highest values of technogenic loads and risks during the researched period were observed for Besarabska Square. It was marked as an area of high risk (observation point No 7). Also increased risk values in the observation period were noted at pollution observation stations (POS) of other central areas of the city (Nezalezhnosti Square, Peremohy Square, etc.).

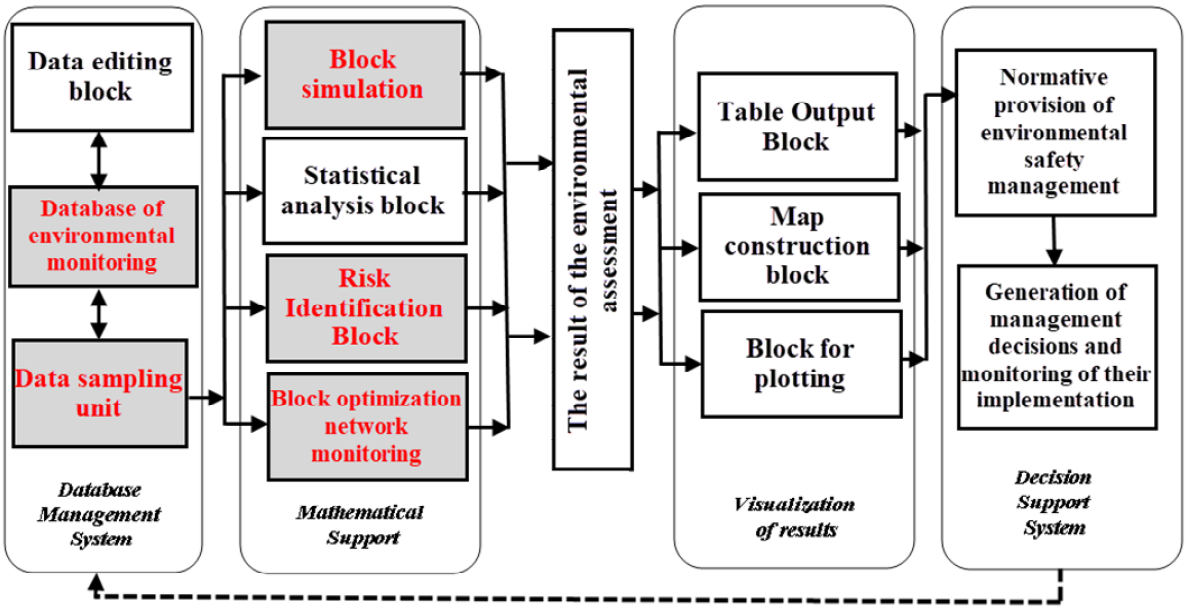

Fig. 1. Created software to provide safety.

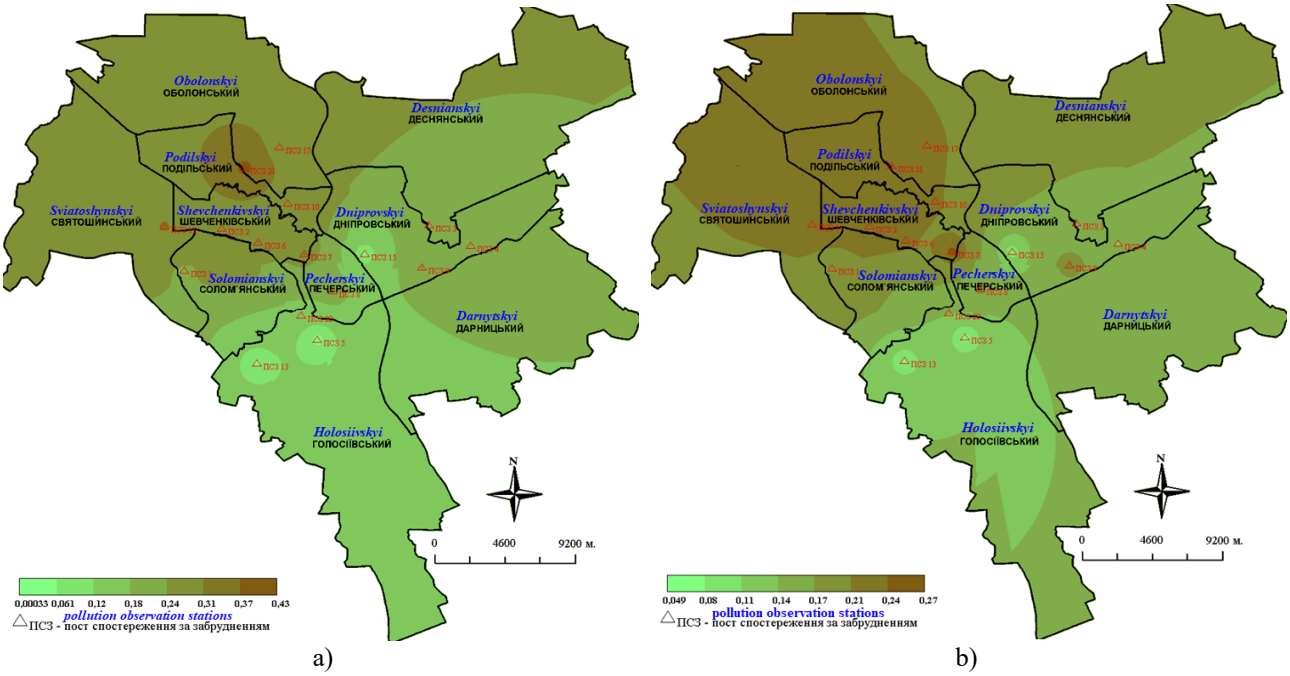

Fig. 2. RITE (a) and RCI (b) as a result of air pollution in Kyiv in January-December 2017 [26].

Table 1. Dynamics of risk values for the health of the population in Kyiv.

Location	2008		2011		2017	
	RITE	RCI	RITE	RCI	RITE	RCI
Peremohy Square	0.298	0.136	0.306	0.210	0.226	0.219
Demiivska Square	0.089	0.060	0.157	0.144	0.160	0.178
National complex "Ekspocentr Ukraina"	0.120	0.053	0.032	0.071	0.067	0.087
Darnytska Square	0.358	0.151	0.215	0.174	0.187	0.182
Maidan Nezalezhnosty	0.390	0.202	0.264	0.212	0.202	0.241
Bessarabska Square	0.472	0.275	0.321	0.255	0.211	0.296
Hydropark	0.140	0.063	0.025	0.068	0.026	0.077

Specialized visual tools of displaying monitoring data on exceeding the maximum permissible concentration levels and corresponding risk values were developed to monitor seasonal dynamics of technogenic loads on individual territories and to identify the most dangerous situations. It is possible to formulate certain sequence of graphic images and to determine the most dangerous deviations from the stable state comparing the results obtained by the authors.

On the first stage it is necessary to outline image of normal state located closer to the origin where exceeding the limit values does not reach critical values. Then it is necessary to distinguish maximum deviations from the norm directed in the opposite direction.

Fig. 3 shows dynamics of atmospheric pollution index for the period from 2015 to 2018 at POS No 7 (district of Besarabska Square). Obtained graph can be considered as the most meaningful reflection of observations results. It takes into account data on main air pollutants in recent years.

Normal values are concentrated closer to coordinate axes five times lower than maximum values. The most dangerous situations form external contour. It starts from point above (6.2016) and is limited by maximum risks shown on the right part of chart.

Separate observations (monthly average pollution data) are indicated by rectangles showing month and year of observation. On the graph the monthly average values are interconnected in order in which the measurements took place.

It is possible to visually identify the most dangerous situations (or periods of maximum deviation from the norm) when local disturbances of stable condition are characterized by significant increase in population morbidity on the adjacent territories. It can be done by the proposed software for monitoring technogenic loads in certain territories.

Indices of ecological status of urban areas were calculated on the basis of monitoring data of Kyiv for analysis of sustainable development processes at local and regional levels, according to the recommendations given in [3]. At the present time the developed software modules were implemented at the Department of organization of civil protection measures of the SES of Ukraine, at separate unit of the Scientific and Technical Center of the state enterprise "NAEK Energoatom" (SE "NAEK Energoatom"). Recommendations on application of the developed software at territorial and interregional units of the State ecological inspection of Ukraine were obtained.

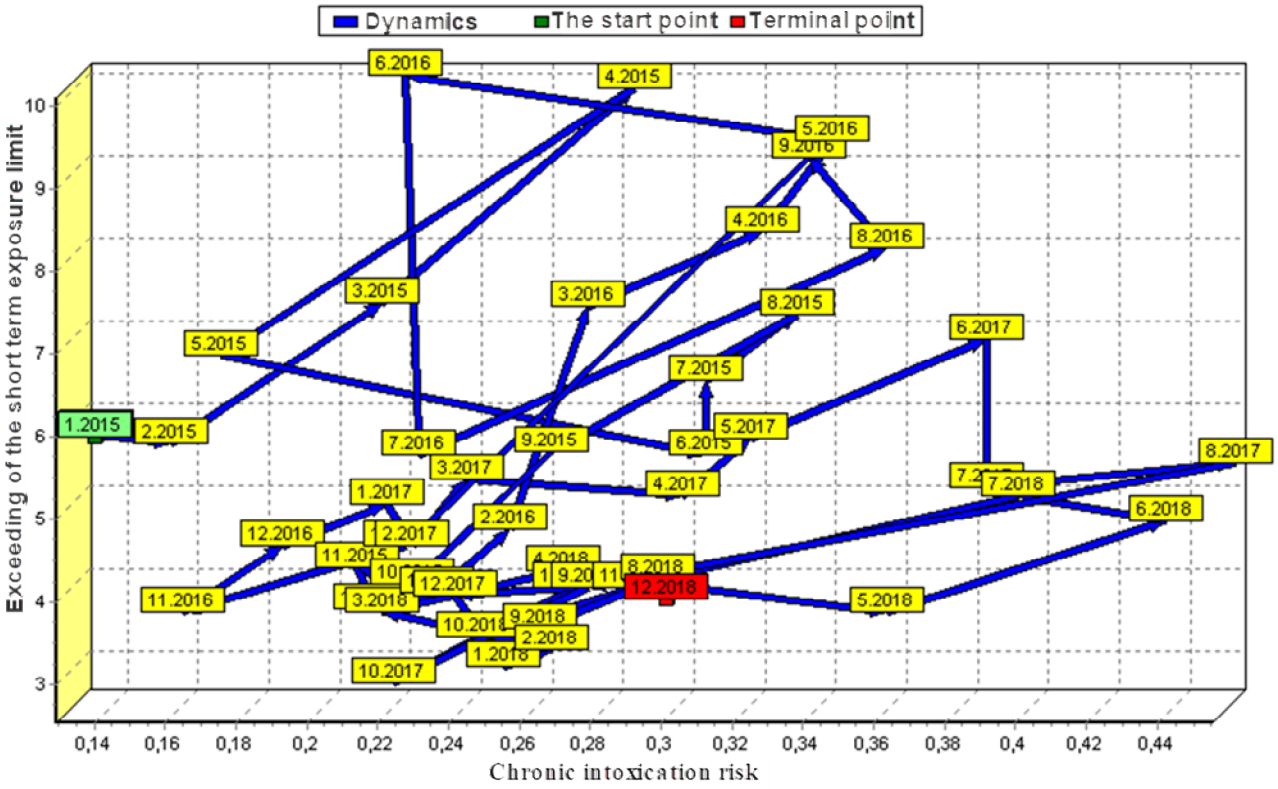

Fig. 3. Dynamic of the atmosphere pollution index at POS No 7 (2015 – 2018).

The developed software can provide population with information about the environment state, existing environmental risks/threats to safe living presented electronically. It is especially important when creating nationwide automated information and analytical system "Open Environment".

There are estimations obtained from the analysis of real monitoring data and modeling of anthropogenic loads on particular areas. They should be correlated with those boundary conditions that meet the criteria of sustainability approved by international and national legislation to determine the boundaries of sustainability of urban areas.

3.4 Application areas of the software tools for advanced training of specialists in the energy sector, environmental and related fields

Application proposals of higher education institutions of Ukraine (National University of Bioresources and Environmental Management of Ukraine, Odessa State Ecological University, State Ecological Academy of Postgraduate Education and Management, etc.) for 2019 were analyzed. Analysis determined that these institutions offer training under the programs of additional professional education - and long-term skills development courses in full-time and part-time forms. The advanced training programs were developed in the field of Earth sciences (meteorology, agrometeorology, hydrology), ecology and others. Courses of advanced training in different directions and topics are offered: assessment of the state and technogenic impact of the motor transport complex on the environment, protection of the atmospheric air, design and operation of modern environmental monitoring systems, training of public environmental inspectors, basics of geoinformation systems and technologies course for users) and others. The offered skills development courses are aimed to improve professional activity of specialists to work in positions of managers and leading executives in management, ecology and nature management. Scientific enterprise "Infotech" developed an innovative virtual environment (consisting of a full-function web-based simulator and a distance training course) for training and skills development of staff of integrated energy system of Ukraine during the distance forms of training in order to improve the qualification of the personnel in the energy sector of Ukraine.

We believe that it is important to implement software tools to support managerial decision-making in the professional development of specialists in the energy, environmental and related fields. It corresponds to the modern world requirements for the training of specialists of new technological era. It will contribute to realization of the sustainable development concept of society. Experts using such software will be able to: identify previously unknown relationships between environmental parameters and environmental factors; identify and predict latent trends and patterns of development of environmental processes (identify hidden factors of influence, including threat factors; systematize and integrate environmental data; develop optimization recommendations in energy, environmental and related industries; prepare preliminary reports and draft feasible decisions, etc.).

In 2019 the authors developed algorithms, mathematical and software tools to test environmental effectiveness of management decision-making. It is an important component in assessing of sustainable development of environmental systems. Also, the authors of this article provide advisory assistance and scientific support to organizations and institutions in order to improve skills of professionals in the energy, environmental and related fields (in particular in application of management decision support software).

4 Conclusions

The software was developed to solve problems of visual analysis of ecological status dynamics of territorial systems and to determine boundaries of sustainability of individual territories. New forms of presentation of monitoring data of anthropogenic loads and risks are presented to analyze the dynamics of anthropogenic impact and to determine the boundaries of stability of local systems. It reflects ecological situation dynamics in the space of informative features.

It is also important to improve skills of professionals particularly in ministries, business and organizational staff responsible for decision-making to reduce negative impact on environment and to train future professionals in this area. Only a few higher education institutions offer training courses for stuff who are working in the sphere of management, ecology and nature use. But it is not paid much attention on training to use managerial decision support software. The main areas of professional development of the specialists responsible for management are: conducting training seminars at the ministries, institutions and departments interested in implementing the developed systems; scientific and methodological support and advisory assistance in the process of implementation of the developed software; development and improvement of educational and methodological support for postgraduate students and trainees of advanced training of specialists responsible for management decisions in energy, environmental and related fields.

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Use of geoinformation systems in environmental monitoring

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Abstract. The purpose of the study, the materials of which are outlined in this article, is to uncover current trends in the development of environmental monitoring and the tracking of anthropogenic environmental impacts. To achieve this goal, it is proposed to use geoinformation systems to perform environmental monitoring and control, using appropriate software. For this purpose ArcGis software was used which allows monitoring the state of the atmosphere, its pollution and other deviations from the norm. The research was conducted exemplified by nine districts of Kharkiv. As a result of computer geospatial analysis, models and maps of urban pollution have been developed. In general, the intellectual analysis of geostatic models of emission distribution in the city allowed identifying and classifying zones of high concentrations of pollution and comparing them with air quality data. Methods of geostatistics transformed the data from a discrete to a continuous form of representation. Further studies in this area may be related to the improvement of geostatistical data analysis and pollution distribution prediction methods. As an example, mathematical formulas were presented to determine the atmospheric pollution index and the true or predicted pollution index, which can be determined on the basis of the data obtained and represented by elements of the ArcGis software package in a discrete and continuous form.

1 Problem statement

The natural environment of Ukraine is contaminated with a large number of various toxic chemical elements and compounds. Under these conditions, the task of ensuring the environmental safety of the population is urgent.

In the implementation of environmental monitoring and environmental control, a common functional element is to conduct observations and evaluate the data obtained by some characteristics. In environmental control, the objects of observation are anthropogenic objects or economic activity as a whole. In the course of environmental control, the managerial influence on the observed object is exercised, in the case of environmental monitoring – obtaining objective environmental data, predicting possible changes in time and space under the influence of natural and anthropogenic factors. The task of observation is to monitor the state of the environment, detect and predict negative changes, and provide timely information in the established manner [1]. In this case, the detection of any deviations in the state of atmospheric air, surface water and soil is a signal for taking control actions to prevent environmental pollution.

Modern technologies allow us to identify environmental problems at the stage of their occurrence, thereby facilitating anthropogenic load on the environment. Significant experience has been accumulated in the world practice in the field of monitoring the harmful effects of human activity on the environment. [2]. At present, objective opportunities and needs for the implementation of various technical and technological measures – special information technologies in the field of ecology – have appeared in Ukraine [3].

The two main methods for tracking the impact on the environment and what is happening in it are monitoring and control. The main difference between them is the dynamism of the first and the static character of the second. The most interesting for analysis is monitoring, which, unlike control, provides more research opportunities and is not so cruel for its purposes. Static control and dynamic monitoring are only external characteristics. In fact, in both cases we are talking about special information technologies [3, 4].

Thus, the topicality of scientific developments in this field becomes clear. The purpose of this article is to reveal the current trends in the development of environmental monitoring and the monitoring of anthropogenic impact on the environment.

2 Analysis of recent research and publications

Modern technologies allow us to explore the environment and make decisions about actions to eliminate the negative consequences of human activity, or support and improve life.

This issue is being addressed both internationally and regionally.

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Research [5] examines the effective use of state-of-the-art technologies for monitoring air conditions using both specialized equipment and portable devices based on the Android operating system. This paper discusses the implementation of an air quality analysis system based on geoinformation systems.

The study [6, 7] proposes the use of specially designed mathematical software for the implementation of environmental monitoring, the task of which is to solve specific problems, taking into account the situation in a particular locality. And as a basis for the implementation of this mathematical apparatus is used geographical information systems.

Ukraine is one of the industrial-agricultural countries. Until recently, the share of heavy industry has been 60% of the country's gross domestic product, which is substantially higher than in Western European countries where the figure is about 35%. It is heavy industry enterprises that form the main man-made burden on the environment. A significant part of industrial enterprises (more than 80%) is located in cities and urban-type settlements. About 70% of the country's population lives here. There are 436 cities and 925 urban settlements in Ukraine. According to statistics, up to 90% of gaseous, liquid and solid wastes are generated in urban areas and about 10% in rural areas. Many cities of Ukraine are characterized by a difficult ecological situation, due to the presence and concentration of enterprises of ferrous and non-ferrous metallurgy, heat power industry, chemistry and petrochemistry, mining and cement plants. Such cities are the leaders in terms of air pollution.

In large cities with large traffic flows, the content of carcinogenic substances of benzopyrene type in the air is 2-3 times, and in the centers of ferrous metallurgy about 12 times higher than in small cities or rural areas. Soil pollution in cities is mainly related to emissions from motor vehicles and industrial enterprises. Pollutants are accumulated or washed out by atmospheric precipitation from the air basin within a radius of 5 km from a stationary source of emissions.

The establishment of environmental management and regulation of environmental processes requires serious technical support and the use of modern technologies to solve problems related to environmental protection. For effective analysis and visualization of spatial information, there exist powerful tools – geographical information systems which not only allow you to create electronic maps based on databases, but also solve problems of any complexity due to the diverse analysis of available spatial information [6, 7].

Modern production, economic and other human activities are associated with the use of a huge amount of various substances, chemical compounds and other materials. This causes a significant burden on the environment, associated with a reduction in living space for untouched wildlife, penetration into the biosphere of substances unusual for their natural circulation, and a violation of the energy balance. The power of this load has reached such a level that it is quite capable of causing serious environmental crises and disasters [8].

Ukraine has significant land resources. As a result of irrational agricultural use, soils lose humus, they are polluted by chemicals, undergo water and wind erosion, are flooded, become salty, and plough land is reduced [9, 10].

The methodology and methodology of using geoinformation technologies in the performance of environmental monitoring is presented in scientific works [8-13].

3 Outline of the basic material

Currently, in the territory of Kharkiv and the region there are a number of environmental problems that cannot be resolved over the years and have an extremely negative impact on the environment. Kharkiv region ranks fifth in terms of industrial production and fifteenth in terms of generation and disposal of industrial toxic waste. The main contribution to air pollution is not made by enterprises (stationary sources of pollution), but by an ever-growing fleet of cars (mobile sources). And this significantly changes the whole map of air pollution in the city.

As a result of the analysis of pollution sources, the following were identified:
- Motor transport.
- Large enterprises – KhTP (KhTZ), CHPP-3 (TETs-3), CHPP-5 (TETs-5), Coke Plant (Koksokhimzavod).

It should be noted that the main pollutants that exceed the maximum allowable concentrations are dust, phenol, formaldehyde, carbon monoxide and soot. Other important factors of the unsatisfactory ecological state in the city are also a decrease in the number of green spaces, lack of sanitary zones of enterprises, natural features, poor management and poor environmental control.

An extremely important problem in the second most populous city of Ukraine is the problem of waste disposal:
- Lack of disposal of most components.
- Low control.
- Absence of private sector garbage collection system.

A vast scale of capital and housing construction, an increase in the population of Kharkiv, due to the dynamics of its development as an industrial and cultural center, led to a significant expansion of the city's borders. Currently, the city covers an area of 303 km^2. Despite its large size, the city is characterized by compactness. A distinguishing characteristic of the city is that it is one of the greenest among the cities of that kind. Green areas of parks and gardens, boulevards and squares make up 12 628 ha. There are more than 17 m^2 of green space for one resident of the city.

The use of geographical information technologies makes it possible to visualize the available data on the contamination of the territory by this or that substance, to perform statistical analysis of the data, to study the distribution of data, to perform their transformation, to compare the existing state of pollution with the maximum allowable concentration.

Modern geoinformation systems, from developers such as: Spatial Manager, ActiveMap GS, GisMapServer, IndorCAD / River, MapInfo MapX, do

not contain tools for monitoring indicators of air pollution by harmful substances, so there is a need to create software applications based on existing geographical information systems using modern methods of geostatistical analysis. A system for monitoring air pollution should allow modeling and analysis of polluted air flows.

In connection with the above, the importance of scientific, methodological and computer support for monitoring tasks, a comprehensive assessment of atmospheric pollution and determining the level of environmental risk for individual territories where modern geographical information technologies and geoinformation systems that provide spatial mapping of territorial objects in the form of electronic environmental maps, plays a decisive role.

The functional diagram of the developed geoinformation monitoring system consists of a data collection subsystem, a data storage subsystem based on geodatabase management systems, a data integration subsystem that allows you to analyze and visualize data using geoinformation and geostatistical methods; subsystems for publishing analysis results in the form of cartographic, tabular materials and reports.

Based on the statement of the problem, a local geographical information systems was developed, designed to assess the technogenic load of the air environment of the city of Kharkiv. Figure 1 shows the structure of this geographical information systems with respect to the direction of movement of accumulated data in the system.

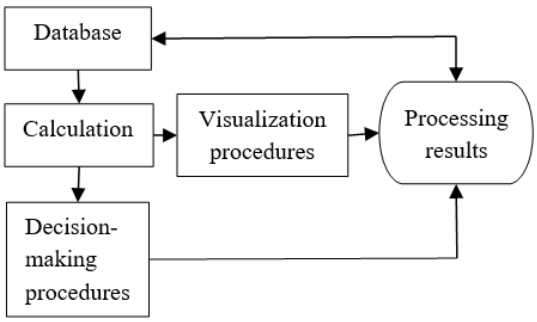

Fig. 1. The scheme of the developed geographic information system.

Using the database allows you to manage your data – to edit and add new records. The system database collects atmospheric air pollution monitoring data for a specific area and is able to add new data and update old records if necessary. Also, the physical properties of pollution sources; maximum permissible harmful substances emissions; digitized terrain maps and substrate maps; data processing results using system procedures should be stored in the database of this monitoring geographical information systems.

Data is one of the most important components of geoinformation systems. Spatial data and related data can be updated with the required amount of time. In the process of spatial data management, geographical information systems integrates spatial data with other types of data, and uses the database to organize and store existing data.

According to the existing data collection system, statistical information describes in the most detailed and complete manner the volumes and locations of major sources of atmospheric emissions. To calculate air pollution in Kharkiv, we used statistical data on environmental emissions for the period 2015 – 2019.

To display the objects of the city's industry, a personal geodatabase with the necessary layers was created [11]. The master plan of the city of Kharkiv, as amended in 2014, served as baseline data. As a result, a digital model of the territory of Kharkiv was made taking into account the number of enterprises – a darker color (Fig. 2).

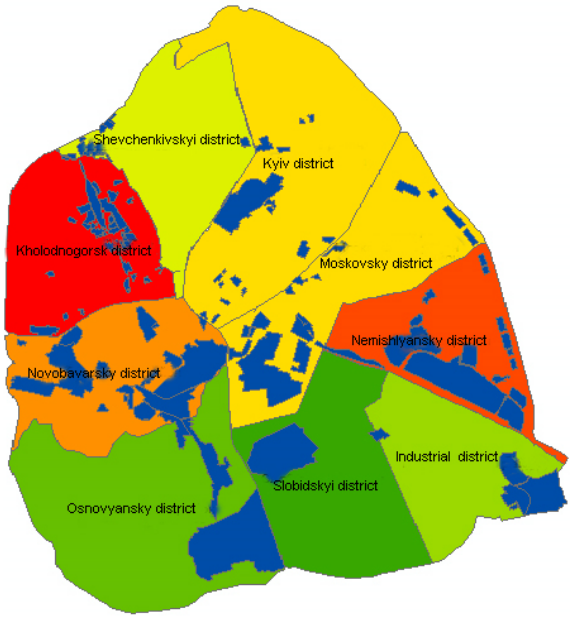

Fig. 2. Digital geoinformation model of the territory of Kharkiv.

The digital model shows that the main concentration of industrial enterprises (namely their share is the highest in pollution) is in Nemyshlianskyi, Kholodnohirskyi and Novobavarskyi districts of the city.

The attribute table of the "Contamination" layer was filled with data over the last five years (Fig. 3).

Having analyzed the amount of emissions of harmful substances into the atmosphere during this period, it was concluded that the amount of harmful substances as a whole is decreasing. The reason for the decrease in the amount of harmful substances in the atmosphere is due to the decrease in capacity in most large industrial enterprises. This conclusion illustrates the comparison of formaldehyde levels in the city air in 2019 (figure on the right) with 2015 (figure on the left) (Fig. 4).

The reasons for the continuing pollution of the atmosphere include the fact that not all operating enterprises which are sources of harmful emissions have built emission treatment facilities. One of the existing cleaning methods is the installation of cyclones (dry cleaning method). But it should be noted that this method of cleaning allows reducing harmful emissions

to the permissible maximum allowable concentrations not in all cases. Only a few companies carry out regular production controls on the emissions and efficiency of treatment plants.

Also, the reason for the unsatisfactory state of the atmosphere is due to the fact that enterprises and organizations have got obsolete equipment that requires being repaired or replaced with a new one. One of the possible ways to reduce the technogenic load on the atmospheric air is closing outdated boiler houses and connecting heat consumers to boiler rooms equipped with modern treatment plants.

The created geographical information model made it possible to obtain histograms, clearly showing the pollutant emissions not only by types of harmful substances (Fig. 5), but also by industries which are the sources of these emissions. The figure shows the city's emission levels in 2018. It was also established that during this time interval the main enterprises that polluted the atmosphere were the "State Specialized Enterprise "Kharkiv State Interregional Special Combine" and the PJSC "Frunze Plant".

In 2015, the emissions of harmful substances were much higher (Fig. 6). The main enterprises from which these emissions were caused were State Enterprise "Malyshev Plant" ("Zavod im. Malysheva") and JSC "Turboatom".

Name of company	Dust 2015	Dust 2016	Dust 2017	Dust 2018	Dust 2019	Sulfur dioxide 2015	Sulfur dioxide 2016	Sulfur dioxide 2017	Sulfur dioxide 2018	Sulfur dioxide 2019
Urban wastewater treatment plants	0,6697	0,49	0,59	0,7	0,89	0,7218	0,4588	0,4502	0,2218	0,7128
Kharkiv Airport	0,6525	0,49	0,59	0,7	0,88	0,7217	0,4666	0,4646	0,2227	0,7188
Ukrelektoremont factory	0,6615	0,48	0,59	0,7	0,83	0,7219	0,4582	0,4535	0,3646	0,7181
Engineering factory	0,6562	0,49	0,58	0,7	0,82	0,7241	0,4558	0,4638	0,2287	0,7244
Autogenous plant	0,6644	0,49	0,58	0,7	0,93	0,7109	0,4692	0,4652	0,2295	0,7169

Fig. 3. View of the fragment of the attribute table of the "Contamination" layer.

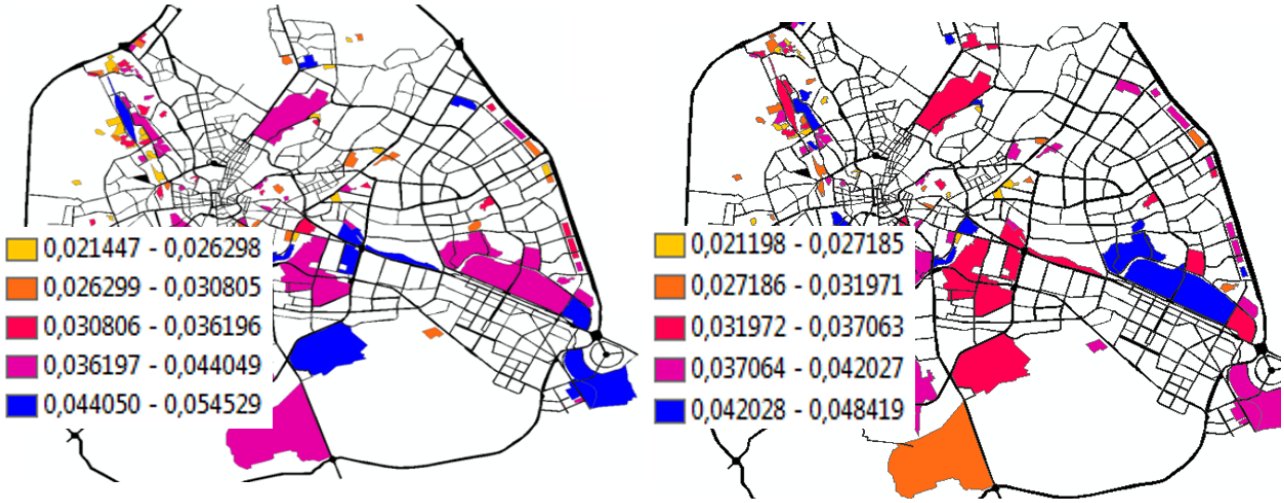

Fig. 4. The formaldehyde (mg/m) level in city air in 2015 in comparison with 2019.

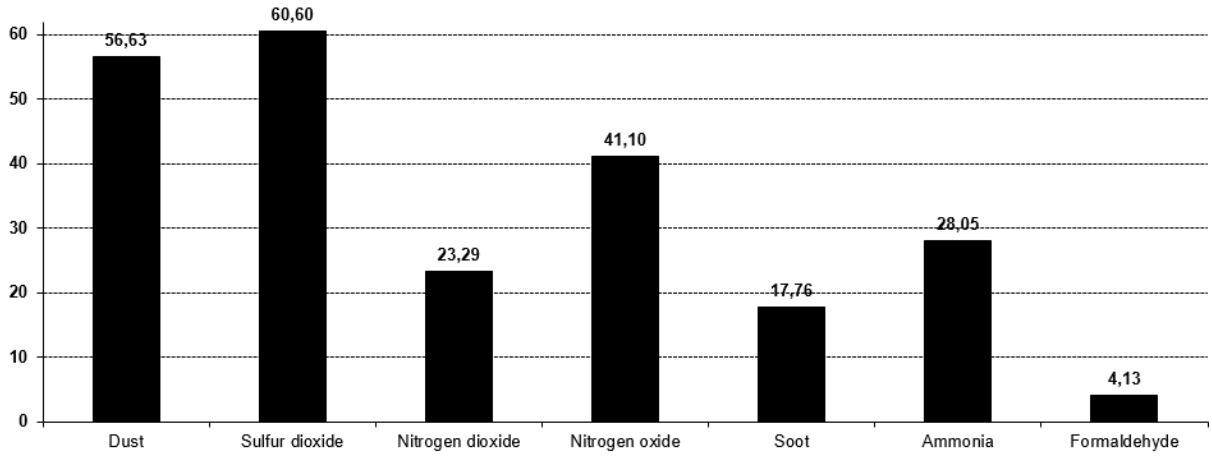

Fig. 5. Emissions of pollutants (thousand tons) into atmospheric air by types of harmful substances.

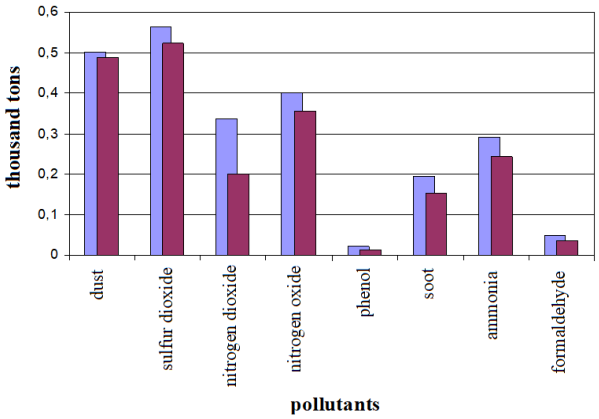

Fig. 6. Comparison of average emissions of pollutants in Kharkiv in 2015 and 2019

Assessment of the technogenic load on the environment, namely on the air environment, may be appropriate when using local geographical information systems map-based monitoring. Unpretentiousness to hardware costs, low cost of development and implementation, flexibility in designing, making amendments and improvements, the ability to build high-precision graphical models within local territories provides this type of geographical information systems advantages compared to a number of global systems existing and presented on the information market. Further development of this geographical information systems should be aimed at assessing, classifying the level of pollution, modeling the form and effects of pollution. For this, two indicators can be used – the air pollution index (*API*) and the pollution index (*PI*).

The air pollution index is used for the integral assessment of the condition of the air. This is a complex air pollution index which is calculated by the sum of several major pollutants when translating the absolute values of each into the maximum allowable concentration (*MAC*). The conversion of absolute values into the air pollution index (*API*) makes it possible to more effectively take into account the environmental damage caused by pollutants of various degrees of harmfulness.

According to state sanitary rules [14], all of the listed indicators have a specific algorithm and formulas for calculation. These formulas are presented below

$$API = \sum_{i=1}^{n} \left(\frac{q_i}{MAC_{iMS}}\right)^{a_i} \quad (1)$$

where n – number of impurities taken into account in the calculation;

q_i – concentration of the i-th substance, mg/m^3; MAC_{iMS} is the maximum single MAC of the i-th substance, mg/m^3;

a_i – the ratio of the hazard ratio of the i-th substance with the harmfulness of substance III hazard class (a_i of I class is 1.7, a_i of II class – 1.3, a_i of III class – 1.0, a_i of IV class – 0.9).

The assessment of the actual or predicted (estimated) level of air pollution is performed by comparing the index of pollution with one substance or the total pollution index (ΣPI) with a mixture of substances with the maximum allowable pollution index (*MAP*). A level not exceeding the *MAP* shall be considered admissible.

Indicator of maximum permissible atmospheric air pollution is a relative integral criterion for estimation of atmospheric air pollution of inhabited places, which characterizes the intensity and nature of the joint action of the whole set of polluting substances (*PS*) present in it. *MAP* is calculated for each case on the basis of experimentally determined and approved in the established order coefficients of combined action (C_{CA}), which reflect the nature of the combined biological action of polluting substances (*PS*) simultaneously present in the atmospheric air. *MAP* is calculated by the formula:

$$MAP = C_{Ca} \cdot 100\% \quad (2)$$

Indicator of actual or predicted air pollution by one substance is calculated by the following formula:

$$PI = \sum_{i=1}^{n} \left(\frac{C}{MAC}\right) \cdot 100\% \quad (3)$$

where C – actual or predicted concentration of a specific substance, mg/m^3;

MAC – maximum allowable concentration of this substance, mg/m^3.

Assessment of air pollution is carried out taking into account the rate of exceeding the *PI* of their normative value (*MAC*) and includes the determination of the level of pollution (permissible, unacceptable) and its degree of danger (safe, slightly dangerous, moderately dangerous, dangerous, very dangerous) [15].

Solving these problems, as well as supplementing the compute core of the system with decision-making and forecasting procedures, are the main areas of further development of the developed geographical information systems.

ArcGis software was used to determine the environmental situation of the city and build the electronic map. The environmental map reflected the spatial features of changes in the state of pollutant emission. The map made it possible to compare the state of environmental pollution by years. An ecological map was also created that provided the opportunity to link the geospatial distribution of industrial enterprises with certain types of pollutants. In contrast, for other pollutants, industrial areas are not a major factor. These findings allow regional managers to develop appropriate stabilization measures.

4 Results

1. A digital geographical information model of the Kharkiv city was developed, with a significant amount of attribute data input.
2. Calculations of maximum permissible indicators of pollutants in the atmosphere.
3. Models of comparison of formaldehyde in city air in 2015 with 2019 have been developed.
4. Models of comparison of pollutant emissions into the atmosphere based on monitoring results are developed.

5 Conclusions

In the study, using the ArcGis software package, ecological models were developed and a map of the level of pollution with harmful substances in the city of Kharkiv was compiled. This map will provide an opportunity to set the necessary operating modes of polluting enterprises so that they do not harm the environment and the population. It will also allow regional leaders to make reasonable and correct decisions regarding environmental activities. The very principle of constructing ecological maps and database structure will be effective at any objects, so the developed geographical information systems can be distributed to any administrative units and industrial enterprises.

In general, an intelligent analysis of the geostatic models of the emissions distribution in a certain territory made it possible to identify and classify zones of high concentrations of pollution and compare them with data on air quality. To process statistical data in a single locality, geostatistical methods were used to transform data from a discrete to a continual representation. Further research in this direction may be related to the improvement of the geostatistical analysis of data and methods for predicting the distribution of pollution. As an example, mathematical formulas were presented to determine the atmospheric pollution index and the actual or predicted pollution index. These indicators can be determined on the basis of the data obtained in the study and presented using elements of the ArcGis software package in a discrete and continual form.

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Methodology for calculating the number of migratory birds in the territory of the wind farms of the Azov region using information and communication technology

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Abstract. A methodology has been developed for calculating the number of migratory birds in the territory of wind power farms and the StatBirds1 program for statistical analysis of bird monitoring results at the wind power farm "Prymorsk-1" on the coast of the Sea of Azov in the Zaporizhzhya Region. In the process of accounting, the type and number of birds, the direction and type of flight (transit, feeding, demonstration), the height and length of the flight, the time each bird was in the observation areas were recorded. Monitoring was carried out during 24 days in 2017 at three observation areas in the territory of the wind farm.

1 Introduction

The capacity of Ukrainian wind power farms (WPF) has tenfold increased in the last 9 years [1]. Ukraine's energy strategy envisages the construction of new WPF, which will be able to produce at least 30% of all electricity from renewable energy sources by 2030 [2]. Taking into account all characteristics of the Pryazovskyi district, it should be stressed that this district has a number of advantages for the wind power farms construction in comparison with other regions of Ukraine. With a small area of the nature reserve fund, there is a small number of objects with environmental status, which predetermined the choice of a location for the placement of several high-capacity wind power farms (Botievo wind power farm, Prymorsk-1, Orlovsk wind power farm, Prymorsk-2).

Botievo wind power farm (capacity 100 mW) is the first largest wind power farm in Ukraine. The "Prymorsk-1" WPF with a capacity of 100 mW produces annually about 700 million kilowatt-hours of clean electricity [2]. This wind power farm is located on the shores of the Azov Sea, where several wind power farms with similar technical parameters are functioning and being built within the 60 km distance.

Current projects and developments in the field of renewable energy create new threats for birds [3]. At the UNO Climate Conference in Bonn, several researchers said that wind turbines are becoming a particular problem for migratory birds. The negative impact of wind power farms on ornithological complexes is greatly exaggerated, since wind power farms are point objects. Their danger to birds does not outweigh the danger of transmition lines, which, in comparison with wind power farms, occupy vast areas. The main threat to birds is caused by the possibility of their collision with the turbines in the case if the wind turbine units are located in places of their intensive movement. In the work [4] it is reported that the death rates of birds at the first small wind power farms are estimated at 2.1–63.8 individuals / a turbine / a year. The technical characteristics of the new generation of rotors provide a threefold negative impact reduction on the birds [5]. A large number of studies have been devoted to the study of the influence of wind power on ornithological complexes [3; 6; 7; 8].

Wind power farms at the Azov Sea seaside are located in one of the most powerful migration routes in Eastern Europe - the Azov-Black Sea route, which predetermined the need to study the state of biodiversity in the territories of wind power farms [9; 10]. Project work to substantiate the impact of wind power farms on bird ornithological complexes within Prymorsk district of Zaporizhzhia region was carried out in 2011-2017 in accordance with the recommendations of the Scottish Natural Heritage Foundation [11]. On the basis of the obtained data, an analysis of the possibility of birds' death in the case of their collision with the rotor blades at the wind power farm Prymorsk-1 was carried out [9].

To estimate the possible number of collisions, information on the total number of collisions on a wind power farm is necessary. As a rule, it is necessary to process a considerable amount of information in order to monitor all this data, the analysis of which is not possible without the application of modern information and communication technologies. The purpose of this work is to develop and test the calculation method of the number of birds in the wind power farms territory. To achieve this goal, the following tasks had to be solved:

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- to conduct the research on ornithological complexes at the observation sites using the recommendations of the Scottish Natural Heritage Foundation,
- to develop ICTs that provide statistical analysis of monitoring results,
- to create the mathematical model for determining the number of birds based on the observation results of bird migration,
- to test the calculation method on the example of monitoring results on the Prymorsk-1 wind power farm territory.

2 Methods of gathering information and statistical processing of observation results

2.1 Physical characteristics of the territory of the Azov Wind power farms

The wind power farms border with the sea of Azov on the south, and are surrounded by agricultural fields from the other sides. There is no natural tree vegetation on the WPF areas, buffer zones and adjacent territories. Tree species are found only in the form of artificially grown plants and along roads. The monitoring of bird migration on the territory of Prymorsk-1, the area of which is 10.1 km^2, was carried out at three points of PS1, PS2, PS3 (Fig. 1), which by their natural parameters are close to the characteristics of the wind power farms and to the areas of all the power farms. The observation site areas of PS1, PS2, PS3 were, respectively, 0.50 km^2, 0.86 km^2 and 1.23 km^2. The total area of observation sites was 2.59 km^2. The location of the PS provided a distance of no more than 2 km between the wind park and the observation point. The observation sector did not exceed 180° for each PS.

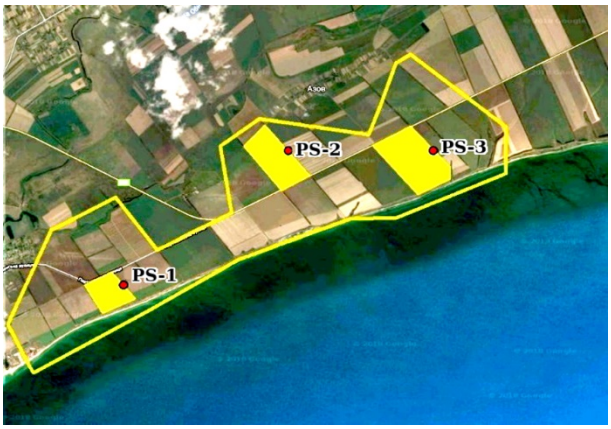

Fig. 1. Scheme of observation points location within the Prymorsk-1 wind park.

2.2 Methods of observation

Methodological developments in the study of ornithological situation in the territory of Prymorsk-1 were based on the recommendations of the Scottish Natural Heritage Foundation [11]. Measurements were made within 24 days in 2017. The duration of observations in different seasons is shown in Table 1.

Table 1. Duration of bird observation in different seasons in 2017.

Observation cycle	Duration of observation T, hours			
	PS1	PS2	PS3	$\sum T_i$
Spring migration	24	24	24	72
Nesting	42	42	42	126
Autumn migration	36	36	36	108
Winter period	42	42	42	126
Total	144	144	144	432

The flight altitude of each bird was recorded at the time of its appearance at the observation area. Subsequently, measurements and bird classification (into several groups) were carried out every 15 seconds. Considering the way of bird interaction with rotors it is possible to distinguish three groups:
- a group of birds with a flight altitude of up to the lower edge of the rotor (48 m),
- a group of birds with a flight altitude above the upper edge of the rotor (182 m),
- a group of birds at risk (RZ) of a collision with rotors at flight altitude between the lower and upper edges of the turbine.

Spring migration was studied in the first and third decades of March, as well as in the first decade of April. The nesting period was studied on April 25-28.04 and May 25-28.05. Autumn migration was studied in the second decade of September, the first and second decades of October and the first decade of November. Winter observation was combined with a wintering period in the second decade of January and a breakup period of wintering in the second decade of February.

The observations were carried out from 8.00 to 11.00 in the morning and from 13.30 to 16.30 in the evening with the determination of the type of birds, their number, direction of flight, type of flight (transit, feeding, demonstration), altitude and length of flight, the total time of the bird presence at the observation site, time spent at various heights.

2.3 The tool base

During the monitoring process, the following equipment was used: binoculars (20x); optical tubes *OPTOLYTH* 20-60x80; optical tube *VIXEN* 20-60x100; optical tube *VIXEN* 20-60x80; a laser device for altitude determining *NICON Forestry* 550; devices for the coordinates determining *GARMIN GPS MAP* 78s.

2.4 Software

The primary processing of the observation results was carried out using the "*WebBirds*" application created by O. Annenkov [10]. The database management system (DBMS) "*WebBirds*" is a convenient tool for storing, accumulating, adjusting and processing the results of bird monitoring at the power farm. The DBMS is based on the tables of the recorded bird species, the number of individuals at various observation points, the territory of

the wind power farm and other parameters of the study. The Web application allows you to create new records from mobile devices, add and update existing data on the number and types of birds, places of their seasonal placement, flight altitude, type and direction of migrations, as well as generate accounting results according to the specified parameters in a convenient form.

To conduct a statistical analysis of the observation results in this work, we created the *StatBirds* program in the *Microsoft Visual Studio Community 2017* software development environment based on *Windows Forms* technology. The program presents the specific parameters that characterize the birds behavior on the territory of the Prymorsk-1 wind power farm: bird species, observation date and time, number (amount) of birds n, number of the observation area PS, flight direction of migrant birds, method (type) of presence at the observation site (transit, stern, demonstrative), the altitude and length of the trajectory in m on this area, the time spent by birds in the observation areas (t_1 – the total time, t_2 – at the height up to the lower level of the wind wheel edge, t_3 – at the height between the lower and upper level of the wind wheel, t_4 – at the height over the upper level of the wind wheel edge), the coefficients k_1, k_2, k_3, k_4, which determine the birds activity at different heights. The values k_1, k_2, k_3, k_4 were calculated by the formula $k_i=t_in_i$, (i = 1, 2, 3, 4).

2.5 Methodology of the migrant number calculation

Let the registration of birds of the j-th species be carried out at the observation site of PS with area S_0 during the time T. Denote the density of birds that are in the air per unit of time, as $n_j(t)$. The total number of birds in flight conditions N_j, per square unit, is equal to

$$N_j = [\int_0^T n_j(t)dt]/(S_0T).$$

T can be divided into smaller intervals $\tau_i=\tau_1, \tau_2, \tau_3...$ with a bird density of n_{ij}. We require that the set of intervals $\{\tau i\}$ contain all the elements of the set $\{t_i\}$ that correspond to the time values t_i of birds in the number n_{ij} at this observation point. In this case, the value of the integral is estimated by

$$N_j = [\int_0^T n_j(t)dt]/(S_0T) \approx (\sum_i n_{ij}\tau_i)/(S_0T). \quad (1)$$

The parameter $K_j = \sum n_{ij}t_{ij}$ in formula (1) characterizes the activity of birds presence at the PS area. If the parameters that determine the migration through the PS area and the adjacent region of square S are the same, then the number of birds of the j-th species in flight condition in region S is determined by the expression

$$N_{jS} = SK_j/(S_0T) = S\sum n_{ij}t_{ij}/(S_0T). \quad (2)$$

The activity coefficient K_j and formulas (1), (2) do not take into account birds on the ground, therefore, the total number of birds in flight condition and on the ground per square unit is

$$N_j = \beta_jK_j/(S_0T) = \beta_j\sum n_{ij}t_{ij}/(S_0T), \quad (3)$$

where the coefficient $\beta_j \geq 1$ depends on the type of bird, time of day, season and other indicators.

In this case, the total number of birds in region S in flight condition and on the ground is

$$N_{jS} = \beta_jSK_j/(S_0T) = \beta_jS\sum n_{ij}t_{ij}/(S_0T), \quad (4)$$

The value of β_j varies over a wide range. It can be expected that for individuals that fly long distances in the spring and autumn seasons, the value of β_j is about 1-5. In the case of local birds that live in this area or constantly move from the habitat to the place of feeding, the value of β_j is most likely in the range of 10-100.

The total density of birds of all species N per square unit in accordance with formula (4) is

$$N = \sum_j \beta_jK_j/(S_0T) = \sum_j(\beta_j\sum_i n_{ij}t_{ij})/(S_0T). \quad (5)$$

Knowing the density (5), we can estimate the total number of individuals of all species N_s on the territory S adjacent to the wind park, according to the formula

$$N_S = S\sum_j \beta_jK_j/(S_0T) = S\sum_j(\beta_j\sum_i n_{ij}t_{ij})/(S_0T). \quad (6)$$

3 Bird monitoring results at observation points and statistical data processing

3.1 Measurement results

In 2017, 5923 birds of 45 species were recorded, 2061 of which were recorded at PS1, 1824 at PS2 and 2038 at PS3. Most of them were in the spring (50%) and autumn (35%) periods. The primary processing of the results was carried out using the WEB application "*WebBirds*" [10]. An example of registration of birds in paragraph PS3, which were recorded during one day on 03/13/2017, is presented in part of the table 2, where the following designations are used: species of birds (*Species of birds*), time of day (*M* – morning from 8.00 to 11.00, *Ev* – evening from 13.30 to 16.30), number of birds of the observed species (*n*), direction of flight *Dir* (*N* – North, *S* – South, *E* – East, *W* – West), type flight – *Type* (*Tr* – transit, *F* – feeding, *Dem* – demo), height (*H*) and flight length (*L*), total time spent by individuals t_1 in point of registration, the time spent by individuals at a height less than the level of the lower edge of the rotor H_1 = 48 m (t_2), the time spent by individuals t_4 at a height greater than the level of the upper edge of the rotor H_2 = 182 m, the time spent by individuals in RZ t_3 at the height between H_1 and H_2, the total activity coefficients of birds presence at the observation point $K_1 = t_1n$ and in RZ $K_3 = t_3n$.

According to the table 2, on the PS3 area, within one day, March 13, 2017, 101 individuals of 9 species were recorded. 71 birds were observed in the morning time, and 30 – in the evening. The greatest activity is related to the species *Sturnus vulgaris* (37 individuals). Most of the birds were found at heights lower than the lower boundary of the RZ, i.e. below 48 m. One *Circus aeruginosus* bird was observed in the RZ at the height of 60 m for 34s. Birds did not fly above the upper boundary of the RZ on this day. The activity coefficient of birds K_1 for all heights on the PS3 site within one day 03.13.2017 is 2570 s., that is two orders of higher than the coefficient value K_3 = 34s, that is related to the RZ. Similar results were obtained at all areas.

Table 2. Monitoring results at PS3 area within one day 03.13.2017

No	Species of birds	M/Ev	*N*	Dir	Type	*H*,м	*L*,м	t_1,s	t_2,s	t_3,s	t_4,s	K_1,s	K_3,s
1	*Circus aeruginosus*	M	1	N	T	60	800	44	10	34	0	44	34
2	*Sturnus vulgaris*		37	SE	K	5	550	30	30	0	0	1110	0
3	*Corvus cornix*		2	E	K	7	550	30	30	0	0	60	0
4	*Larus ridibundus*		6	E	T	10	830	46	46	0	0	276	0
5	*Corvus frugilegus*		5	NW	K	7	650	36	36	0	0	180	0
6	*Larus ridibundus*		10	SW	T	15	800	44	44	0	0	440	0
7	*Larus ridibundus*		10	W	T	15	830	46	46	0	0	460	0
The amount of measurements in the morning			71									2570	34
1	*Falco tinnunculus*	Ev	1	NE	K	25	700	39	39	0	0	39	0
2	*Streptop.decaocto*		2	N	K	5	400	22	22	0	0	44	0
3	*Larus ridibundus*		7	E	T	10	780	43	43	0	0	301	0
4	*Larus ridibundus*		3	E	T	15	780	43	43	0	0	129	0
5	*Circus aeruginosus*		1	NW	K	30	830	46	46	0	0	46	0
6	*Larus cachinnans*		3	S	T	10	480	27	27	0	0	81	0
7	*Corvus frugilegus*		12	N	K	7	550	30	30	0	0	360	0
8	*Falco tinnunculus*		1	W	K	25	700	39	39	0	0	39	0
The amount of measurements in the evening			30									1039	0
Total number of measurements in the morning and evening			101									3609	34

The vast majority of birds in winter period (86.9%) were recorded at heights of up to 10 m. 13.1% of individuals were in the range of 10-50 m. No birds were found in the risk zone of 51-150m. The main migration vectors were the east (31.21%) and the southeast (23.76%). The number of migrants in the southern (11.83%) and north-eastern (11.73%) directions was two times lower. For each of the other areas, about 6% were taken into account, Fig. 2.

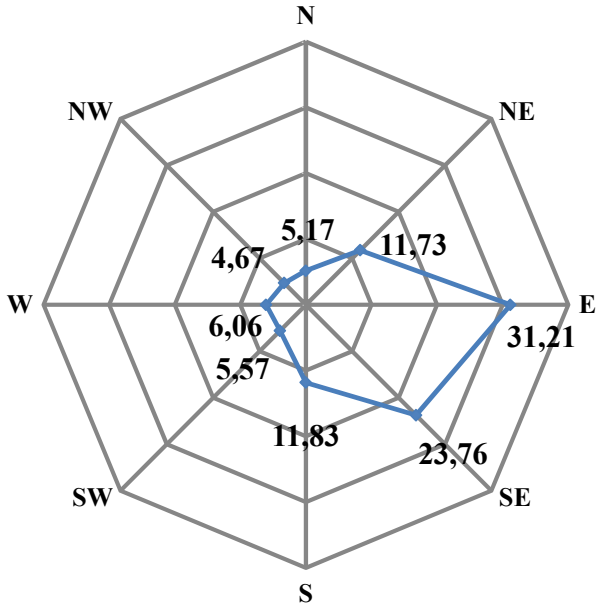

Fig. 2. Directions of bird movements in winter period (quantity in %).

In the spring migration period, 98.4% of birds were recorded at the safe heights of up to 50 m. 1.6% of all recorded birds were found in the risk zone. About half of the birds (67.9%) flew to the northwest, north, northeast and east. Additional flight directions were the southwest (12.1%) and the southeast (9.4%), Fig. 3.

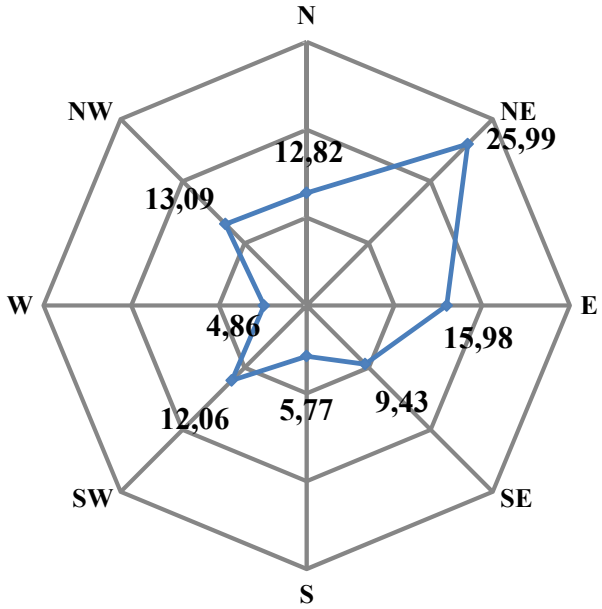

Fig. 3. Directions of spring migration of birds (quantity in %).

Altitudinal movements of birds in the nesting period were distributed as follows. All birds at heights of less than 50m were recorded. The vast majority of birds were observed in the surface altitude range up to 10m (92.4%). This nature of the altitudinal distribution is explained by

the fact that most birds at this time of year are in their nests. The main directions were the north, the northeast, the east (only 55.1%) and the southeast (22.0%), Fig. 4.

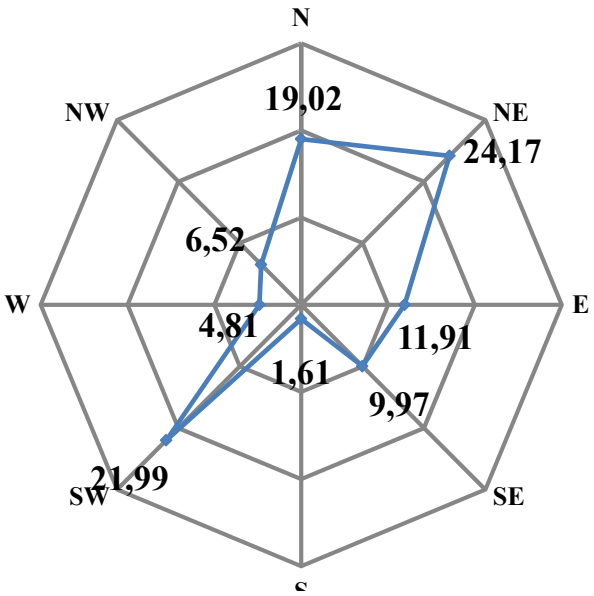

Fig. 4. Direction of bird flight in the nesting period (quantity in %).

Observations of autumn migration showed that 99.4% were at safe altitudes. In the risk zone, 6 birds were recorded (0.6%). The main directions of migration were the northeast, the east and the southeast (68.8%), Fig. 5.

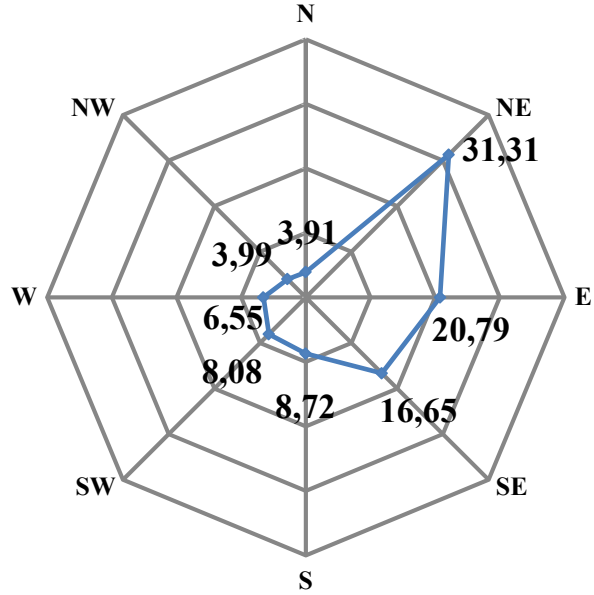

Fig. 5. Directions of autumn bird migration (quantity in %).

Statistical processing of bird monitoring results was carried out using the *StatBirds* program. The number of registered birds of various species in 2017 in the most dangerous altitude range (RZ) is given in table 3. The general coefficient of activity K_3 for them turned out to be equal to K_3 = 2196 s, which is two orders less than the value K_1 = 170048 s, which relates to the entire ornithocomplex.

It follows from the Table 3 that 72 birds were found in the RZ at altitudes between 48 m and 182 m. Most of them belong to *Larus ridibundus* (43 birds) and *Merops apiaster* (15 birds). The number of individuals for *Buteo buteo* and *Circus aeruginosus* was 5 and 9, respectively.

Table 3. Bird monitoring results in RZ on all observation areas.

Bird species	Season	Area number(s): the number of birds *n*	*t*, s	K_3
Buteo buteo	Summer	1,2,3: 0	0	0
	Autumn	1: 1,1	36,7	43
	Autumn	2: 1,1	51,30	81
	Autumn	3: 1	18	18
	Winter	1,2,3: 0	0	0
Circus aeruginosus	Spring	1: 1,1,	51,19	70
	Spring	2: 1,1	18,40	58
	Spring	3: 1,1	34,40	74
	Summer	1,2,3: 0	0	0
	Autumn	1: 1	25	25
	Autumn	2: 1	30	30
	Autumn	3: 1	72	72
	Winter	1,2,3: 0	0	0
Merops apiaster	Spring	3: 15	33	495
	Summer	1,2,3: 0	0	0
	Autumn	1,2,3: 0	0	0
	Winter	1,2,3: 0	0	0
Larus ridibundus	Spring	1: 5,7,3,8	42,25; 19,26	650
	Spring	3: 7	42	294
	Summer	1,2,3: 0	0	0
	Autumn	3: 7,6	28,15	286
	Winter	1,2,3: 0	0	0

The average density of the total number of birds in flight condition N and on the ground per square unit is determined by the formula (5). The parameter β_j in this formula depends on the type of individual, time of day, season, terrain characteristics, etc. Let's suppose that the average value of β_j is 30.

In this case, the total number of birds in flight condition and on the ground on three areas PS1, PS2, PS3 will be 4.8. The characteristics of the observation points and the surrounding areas of the power farms are identical. The coastal area, where four wind power farms are located, is approximately 10^3 km^2. The total number of birds in this zone and at the Prymorsk-1 power farm according to formula (6) is 18.8 and 4800, respectively.

3.2 Distribution of birds in flight condition by monitoring areas

The density of birds at different areas of observation is determined by formula (5), where the coefficient β_j should be set equal to 1. The calculation results are presented in the table 4. When compiling the table 4 the following designations were accepted:

N is the estimated value of the number of birds in flight condition (in brackets is the average value of the number of recorded birds a, referred to one day of registration on the area of 1 km^2),

N_m, N_{Ev}, a_M, a_{Ev} – the same separately for morning M and evening Ev observations,

N_{Tr}, N_{St}, a_{Tr}, a_{St} – the same for birds with different types of flight (transit Tr and feeding St, respectively),

N_E, N_{SE}, a_E, a_{SE} – the same for birds per day, with the preferred direction of migration in the eastern *E* and the southeast *SE* directions, respectively.

From the table 4 it is obvious that the average number of birds a, recorded in various cases, is three orders of magnitude greater than the number of birds *N* that are only in-flight condition.

Table 4. The calculated total number of birds in flight condition N_F and the number of recorded birds *a* (in brackets) when measured per 1 km^2.

	PS1	PS2	PS3
$N(a)$	172 (0.366)	88 (0.149)	69 (0.083)
$N_M(a_M)$	85 (0.179)	45 (0.075)	38 (0.047)
$N_{Ev}(a_{Ev})$	87 (0.187)	44 (0.074)	31 (0.036)
$N_{St}(a_{St})$	63.5 (0.127)	34.2 (0.058)	48.5 (0.026)
$N_{Tr}(a_{Tr})$	108.5 (0.239)	54 (0.091)	47 (0.057)
$N_S(a_S)$	48 (0.084)	19.5 (0.030)	20.6 (0.026)
$N_{SE}(a_{SE})$	32 (0.067)	17.7 (0.032)	11.9 (0.012)

Morning and evening measurements do not differ greatly from each other. Most of the birds flew in transit, while the eastern and south-eastern directions of migration were the main ones. The activity of birds at different areas of observation was different. The highest activity was recorded at PS1. There is a linear correlation between the parameters *N* and *a*

$$N = A + Ba \tag{7}$$

The table 5 presents the correlation coefficients K_{Na}, between the values of *N* and *a*, calculated for each observation area and in general for all areas using the formula

$$K_{Na} = \frac{\sum N_i a_i - n N_a a_a}{n s_N s_a} \tag{8}$$

where N_a, a_a, s_N, s_a are equal

$$N_a = \sum N_i / n, \qquad a_a = \sum a_i / n,$$

$$s_N = \sqrt{\sum (N_i - N_a)^2 / n}, s_a = \sqrt{\sum (a_i - a_a)^2 / n}. \tag{9}$$

The values of the coefficients *A* and *B* were calculated by the formulas

$$B = s_N K N_a / s_a, A = N_a - B a_a. \tag{10}$$

The significance of the correlation coefficients for *n*-2 degrees of freedom was determined using Student's *T*-criterion. The calculated values of this criterion for observation areas PS1, PS2, and PS3 were 31.20, 59.83, and 3.81, respectively, which exceeds the critical value T_{cr} = 2.01 and, therefore, allows to present the correlation dependence in the form of *a* regression equation (7). The correctness of the use of regression equations is confirmed by a small standard deviation *s* of the values of *N* from table 5 from the values calculated using the correlation equations. In the most disadvantageous case, the value of *s* is about 0.021.

Table 5. Correlation coefficients K_{Na}, critical value T_{kr}, regression coefficients *A* and *B* in equation (7) per 1 km^2 and standard deviation *s* of the calculation results by formula (7) from the values calculated by formula (5) for individual areas and on average by all areas Σ.

	PS1	PS2	PS3	Σ
K_{Na}	0.997	0.999	0.863	0.970
T	31.20	59.83	3.81	17.35
T_{kr}	2.01	2.01	2.01	1.73
A	-0.010	-0.00058	0.00028	-0.0271
B	0.00221	0.00170	0.00107	0.00225
S	0.0068	0.0014	0.011	0.021

3.3 The distribution of birds by seasons

Analysis of the distribution of birds by seasons was carried out using observational data in winter, in the spring migration period, in the nesting period and in the autumn migration period, shown in Fig. 2-5. The calculations took into account all species of birds recorded in the morning and evening times at all three areas, flying at all altitudes. The correlation coefficient K_{Na} between the calculated number of birds in flight condition and the measurement results in this case is 0.97, Student's criterion at 5% significance level for *n*-2 degrees of freedom *T* = 5.94, critical value T_{cr} = 2.92. Since $T > T_{cr}$, the correlation dependence $N(a)$ is significant and the regression equation (7) can be constructed using formulas (10) in the form

$$N = 0.037 + 0.00092a. \tag{11}$$

Comparative data obtained by formulas (5) and (11) are presented in table 6.

Table 6. The average number of recorded birds *a* in flight condition measured per day and 1 km^2 and the results of calculating the number of birds *N* by the formula (5) and N_{Regr}, by the formula (11).

	Winter period	**Spring migration**	**Nesting**	**Autumn migration**
a	99	139	59	130
$K = \sum n_i t_i, c$	11695	26040	11607	22160
N, formula (5)	0.135	0.172	0.090	0.147
N_{Regr}, formula (10)	0.129	0.166	0.092	0.157

In this case, the standard deviation of the experimental values from the values calculated using the regression equation is 0.0069.

3.4 Resume

The Azov-Black Sea coast of Ukraine contains unique steppe plant habitats with numerous populations of migrating birds on the Eurasian scale, therefore the state of biodiversity monitoring on the territory of the wind

power farm is of great importance. The movement of birds in different phases of their life cycle (nesting period, spring and autumn migration, wintering) are significantly different from each other. The largest number of birds were recorded during spring and autumn migrations. The used estimate of the number of migratory birds and their total number at a given time implies monitoring of the observation sites in accordance with the recommendations of the Scottish Natural Heritage Foundation [11]. It is based on the use of formulas (1) – (11), in which the main parameter is the coefficient $K = \sum n_i t_i$.

The value K characterizes the activity of birds presence on the area. Calculation of the K value allows us to estimate the average number of migrating birds N at a given moment of time, not only on this area, but also in the territory adjacent to it.

From general considerations, it is clear that the value of N depends on the movement speed of individuals, their flight trajectory and many other parameters. A statistical analysis of the results of monitoring the territory of the Prymorsk-1 wind power farm showed that in reality it is determined by one integral characteristic by coefficient K. The correlation coefficient between the average number of migrants that are at the observation point and the registered number of birds a crossing this area is estimated by value of 0.97. Moreover, the Student's criterion, which determines the significance of the correlation coefficient, is at least 5.9, which is several times higher than the critical value.

In conclusion, we will carry out a general analysis by combining all the observation results presented in Table (4) - (6). The resulting regression equation has the form

$$N = -0.0105 + 0.00182a. \quad (12)$$

In this case, the correlation coefficient between the number of birds in the air and the counting results is 0.91. The Student's criterion, which determines the significance of the correlation coefficient, is about 10.5, which is more than six times the tabular value of 1.71. A graphical interpretation of the dependence of N on a is shown in Fig. 6. The straight line in this figure is constructed using the regression equation (12), and the points correspond to experimental data.

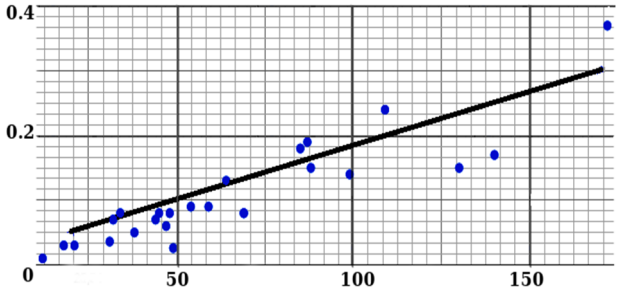

Fig. 6. The correlation dependence between the measured number of birds a and the number of individuals N currently in flight condition.

The Fig. 6 shows that the experimental points are generally consistent with the regression equation (12). The inaccuracy of using formulas (3) and (5) for determining the number of birds per square unit depends only on the error in determining the coefficient of birds activity $K = \sum n_i t_i$. This inaccuracy does not exceed 3-5 seconds, which can lead to an error in calculating the parameter K by no more than 5-10%. The main reason for the scatter of points in Fig. 6 is caused not so much by the error in determining the parameter K as by the statistical spread of the recorded data results depending on the season and the selected observation point for accounting.

4 Conclusions

In the work, the behavior of bird ornithological complexes in the territory of the Prymorsk-1 wind power farm in 2017 was studied using the recommendations of the Scottish Natural Heritage Foundation. During the observation, 5923 birds of 45 species were recorded. A statistical analysis of the observation results was carried out and a group of birds at risk zone of collision with turbines of a wind power farm was identified (*Larus ridibundus* – 43 birds, *Merops apiaster* – 15 birds, *Buteo buteo* – 5 birds and *Circus aeruginosus* – 9 birds).

The *StatBirds* program was developed for statistical analysis of the observation results and a mathematical model for calculating the number of birds in flight condition and on the ground. The number of birds in the territory of the wind power farm was estimated basing on the monitoring results in the winter, spring and autumn periods. According to the calculated data, the average number of birds of all species on the territory of the Prymorsk-1 wind power farm is about 18.8 individuals. Correlation dependencies between the number of individuals in flight state and the number of birds recorded at the observation areas were found.

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Environmental monitoring and recommendations on decreasing the levels of pesticide pollution in Zhytomyr region of Ukraine

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Abstract. Environmental monitoring was conducted of facilities for storage and disposal of banned and unsuitable pesticides. Pesticide content in the soil, water, and products of agriculture in the Zhytomyr region of Ukraine was examined, and the accumulation of organochlorine pesticides by freshwater bivalve mollusks was assessed. Storage facilities of the Zhytomyr region contain nearly 392.18 t of pesticides in 137 warehouses, of which 11 meet the requirements, 36 are tolerable, and 90 are in poor condition. In 2018–2019, pesticide content (dichlorodiphenyltrichloroethane (DDT), heptachlor, dichlorodiphenyldichloroethylene (DDE), dichlorodiphenyldichloroethane (DDD), hexachlorocyclohexane (HCH)) was studied in soil and sediments in the Zhytomyr region. The content ranged from 0.0007 to 0.07 mg/kg, which is lower than MPC (0.1 mg/kg). The content of HCH, DDT, DDE, DDD, and heptachlor was at 0.0007–0.01 mg/dm^3 levels in water bodies of the Zhytomyr region in 2018–2019, also lower than MPC. In some samples of soil, water and vegetables, the recorded levels of DDT and organophosphate pesticides Dragon, Dorpan, and Dursban exceeded MPC in 1.5–3.0 times. Traces of organochlorine pesticide Aldrin were found in soft tissues of bivalve mollusks and in the sediments of water bodies they inhabit. Recommendations are proposed to lower the pesticide content in the environment.

1 Introduction

Ukraine has ratified the Stockholm Convention (23 May 2001) with the Law of Ukraine N 949-V (949-16) of April 18, 2007. According to the Convention, persistent organic pollutants (POP) are recognized as toxic, resistant to decomposition, bioaccumulative, and are subject to transboundary movements by air, water and with migrating species. POP is also deposited at a great distance from the source of their emission, accumulating in terrestrial and aquatic ecosystems [1]. By this convention DDT, aldrin, dieldrin, endrin, chlordane, mirex, toxaphene, heptachlor are included in the list of most dangerous substances.

Long-term application of pesticides has led to large-scale environmental pollution over huge territories. The migration of toxic compounds in ecosystems causes the accumulation of residual amounts of pesticides in natural objects.

Organochlorine pesticides (OCP) have been widely used, and some of them still are used in Ukraine [2–7] and other countries [1, 8–14] to control insect pests of agriculture and protect crops. Such as OCP as
DDD (dichlorodiphenyldichloroethane),
DDT (dichlorodiphenyltrichloroethane),
DDE (dichlorodiphenyldichloroethylene), and
HCH (hexachlorocyclohexane) are highly persistent, accumulate for a long time in plants, animals, soils, and are poorly soluble in water. Therefore they usually accumulate in considerable concentration in river sediments and silt.

In Ukraine, OCP has been used most extensively in the 1950-1960s. At the beginning of the 1970s, OCP was shown to be highly toxic to animal organisms. They are also very persistent. DDT does not decompose in the environment for 10 years [6]. When from the environment (soil, water, sediments) OCP enter the living organisms, the compounds circulate in trophic chains of local ecosystems, climbing the trophic levels. Thus, all these components of ecosystems, from producers to consumers of highest levels, contain pesticides in their bodies. DDT and HCH can accumulate in various organs and tissues (in the case of DDT, mostly in fat tissue). OCP is polytropic compounds, thus they are significantly dangerous to human and animal organisms even in small doses. They negatively affect the functional state of the liver, glands, kidneys and other organs. They have also cytotoxic, carcinogenic, mutagenic effects. All this led to the restriction or ban of their use in the early 1970s. But even today, OCP belongs to the category of widespread pollutants both in Ukraine and abroad.

Content of DDD, DDT, DDE, HCH, DDVP (dichlorvos), 2,4-D (2,4-dichlorophenoxyacetic acid) has been analyzed in rivers of Luhynsky district of Zhytomyr region in 1988-2008. The results of the analysis indicated a significant decrease in pesticide content in the two

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decades [4]. That is linked to the discontinuation of large agricultural enterprises that had used public funds to purchase pesticides. At present, only small farms and private homesteads operate in the district.

The long-term, often uncontrolled and unjustified, use of pesticides in agriculture has led to the contamination of inland water bodies with these dangerous toxicants and the disturbance of natural ecological balance. Pesticides of different chemical origin have a detrimental effect on all representatives of freshwater biota. Due to the cumulative properties, pesticides circulate and accumulate in the organisms of all aquatic organisms, including shellfish. In the early XXI century, several scientists [6] have registered persistent OCP (DDT and HCH) in various organs of six freshwater mollusk species of the family Unionidae in rivers of Zhytomyr and Khmelnytskyi regions.

In the summer of 2008, several pesticides (DDT, DDE, DDD, HCH, aldrin, dieldrin, and hexachlorobenzene) have been found in bivalve mollusks *Colletopterum ponderosum sedakovi* (Siemaschko, 1848) in Lake Baikal [8].

I. A. Fodchenko [7] has found pesticides (DDT, aldrin, HCH, heptachlor) in mussels, produced in Ukraine (the Black Sea coast of Odesa region) and abroad (Chile, China). Pesticides have been found in marine mollusks from other countries: Korea [9], Croatia [11], Italy [12], Asian countries [14] and others.

Today, organophosphate pesticides such as chlorophos, paraoxane, metaphos, carbofos, oxamethyl are used more and more frequently [3]. They are less toxic than OCP and do not withstand water, i.e. they are subject to rapid decomposition, which eliminates their prolonged impact on the biota of reservoirs. Today it is important to monitor both the storage conditions of pesticides, a lot of which are still kept in the Zhytomyr Region of Ukraine [15], and the pesticide content in the soil, water bodies, products of agriculture, and in aquatic organisms.

Study aim: to conduct ecological monitoring of pesticides in the Zhytomyr region and to prepare recommendations on decreasing the pesticide levels in the environment.

2 Material and methods

Study object is pesticide storage warehouses; samples of water, soil and products of agriculture from Zhytomyr region; freshwater bivalve mollusks of the species *Unio crassus* (Retzius, 1783) from Perga river (Radovel' village, Olevsky district of Zhytomyr region) (Fig. 1) and *Anodonta anatina* (Linnaeus, 1758) from Irsha river (Khoroshiv village, Zhytomyr region) (Fig. 2).

The study subject is the ecological monitoring of pesticides in the Zhytomyr region.

The content of pesticides in water, soil, agricultural products and tissues of mollusks was determined based on the State Institution "Zhytomyr Regional Laboratory Center of the Ministry of Health of Ukraine" using standard methods of OCP research, gas-liquid chromatography, and thin-layer chromatography: DSTU EN 1528-1-2002; EN 1528-2:1996; EN 1528-3:1996; EN 1528-4:1996; DSTU EN 12393-(1;2;3):2003; DSTU 4514:2006 [16–18].

Fig. 1. The shell of *Unio crassus* (Retzius, 1783) from the Perha river (Radovel' village of Olevsky district, Zhytomyr region).

Fig. 2. The shell of *Anodonta anatina* (Linnaeus, 1758) from the Irsha river (Khoroshiv village, Zhytomyr region).

Information about pesticide storage was given by the Department of Ecology and Natural Resources of Zhytomyr Region State Administration.

Bivalve mollusks were sampled manually at a maximum depth of 0.5–0.7 m [19]. Most mollusks live on sediments (silt, sandy silt), rarely on sands. Species identification of mollusks was performed based on their conchological features [20].

The results of the study were processed using methods of variation statistics [21].

3 Results and discussion

3.1 The problem of pesticide storage facilities in Zhytomyr region

Numerous warehouses were built in almost all regions of then-Soviet Ukraine to store various types of pesticides (herbicides, fungicides, insecticides, acaricides, zoocides, etc.). Usually, such pesticides are stored in significantly damaged packages, contaminate the soil and seep into the groundwater. Hence, warehouses that contain pesticides are extremely dangerous. They also have no warning signs and are largely unsecured.

One of the acute environmental problems in the Zhytomyr region is the practice of dealing with unsuitable pesticides and agrochemicals. According to the Department of Ecology and Natural Resources of Zhytomyr Region State Administration, 137 warehouses

with unsuitable pesticides and agrochemicals are in the Zhytomyr region, as of 01.01.2018 (Fig. 3). Eleven warehouses meet the requirements, 36 are tolerable, and 90 are in poor condition (Fig. 4, 5). The largest warehouses are located in Yahodynka village (Pulynsky district), with 23.00 tons of pesticides; N. Velidnyky village (Ovrutsky district), with 19.49 tons of pesticides at OJSC "Ovrutsky rajagrokhim"; Koshelivka village (Pulynsky district), with 17.0 tons of pesticides; Veselivka village (Ovrutsky district), with 12.07 tons of pesticides at LLC "Nehodivske".

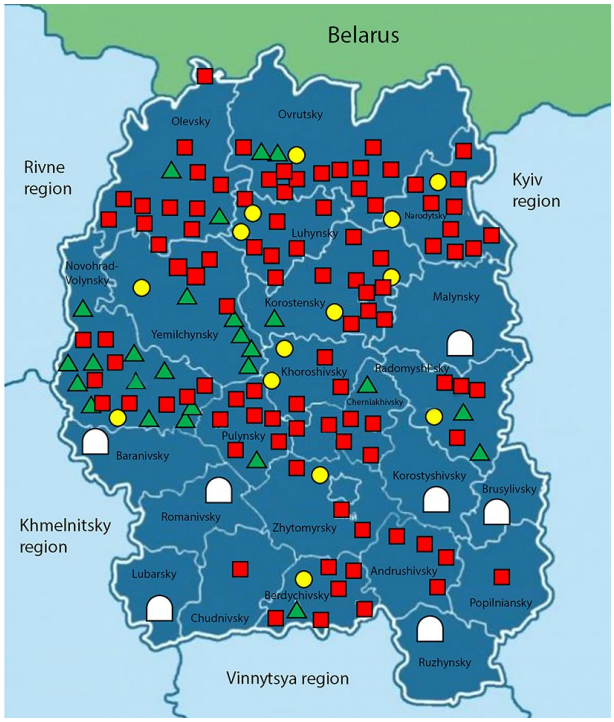

Fig. 3. Map of warehouses storing unsuitable pesticides and agrochemicals in Zhytomyr region, as of 01.01.2018: triangle – under 0.5 t of pesticides; circle – 0.5–1.0 t of pesticides; square – more than 1.0 t of pesticides; horseshoe – pesticides were utilized in 2012.

Fig. 4. Pesticide storage in Toporische village of Khoroshiv district, Zhytomyr region (October 2019).

There are a total of 392.18 t of stored pesticides. Of these, 32.450 t are liquid, 24.975 t are solid, and 334.755 t is unknown mixtures. The condition of the storing containers is as follows: 39.07 t of pesticides are kept in good condition, 22.43 t in satisfactory condition, the rest in poor condition. Due to poor storage conditions, toxic pesticides enter the environment including water and air, presenting the risk of poisoning to humans, flora, and fauna.

Fig. 5. Pesticide storage in Znamianka village of Khoroshiv district, Zhytomyr region (October 2019).

Only warehouses storing unsuitable chemical plant protection products (CPPP) in Berdychiv and Pulyn districts are protected, the rest of the warehouses are not guarded. In the Zhytomyr region, efforts were made of replacing CPPP containers. For example, 33.731 t of unsuitable agrochemicals of the former collective agricultural enterprises were weighed and reloaded in 11 village councils in Korosten district, in October 2014. 37 t of toxic waste were reloaded in sealed containers at the territories of Novovelidnytska, Nevhodivska, Mozharivska and Pokalivska village councils of Ovrutsky district in 2014. Popilnanska united territorial community (UTC) organized reloading at its own expense of 5.5 t of CPPP to sea containers in 13.05.2017.

In 2011–2012, 968.535 t of unsuitable CPPP were reloaded and exported from Ukraine. At present, the territory of Baranivsky, Brusyliv, Lubarsky, Malynsky, Romanovsky, and Ruzhyn districts of the Zhytomyr region has been cleared of CPPP.

Expired pesticides are unusable and must be disposed of. Together with storage packaging, they are hazardous waste that must be correctly deactivated by licensed agencies. Currently, in Ukraine, there are no entities licensed to conduct hazardous-waste management (collection, transportation, storage, treatment, disposal), including unsuitable pesticides.

The problem also lies in the lack of a scientifically sound concept of pesticide processing and deactivation, imperfect technological processes and the incomplete technological cycles of processing, the lack of safe methods of disposal. The whole range of issues related to the elimination or control of the negative effects of toxic waste on the environment and human health will only be effectively resolved with a national program for waste

management.

3.2 Pesticide pollution of soil, water bodies and products of agriculture in Zhytomyr region

According to State Institution "Zhytomyr Regional Laboratory Center of the Ministry of Health of Ukraine", pesticide (HCH, DDT, DDE, DDD, heptachlor) content was in the range of 0.0007–0.07 mg/kg in soils and sediments of Zhytomyr region in 2018–2019, within the MPC values (0.1 mg/kg) (Table 1).

Table 1. Levels of pollution of soil and sediments with residual amounts of pesticides (mg/kg, MPC = 0.1 mg/kg) in Zhytomyr region (2018–2019).

Waterbody	District	Concentration Pesticide	
		2018	2019
"Stas'ka hreblia" UT MR	Andruchivka city	0.008 HCH 0.005 DDT	0.008 HCH 0.005 DDT
Unorganized recreational area in Kvitneve village	Andrushivsky	0.01 HCH 0.005 DDE	0.009 HCH 0.005 DDE
Pond of Vchorayshe village	Ruzhyncky	0.01 DDD	0.008 DDD
Lake No.1	Korostyshivsky	0.004 HCH	0.004 HCH
Lake of Glybochok village	Korostyshivsky	–	0.02 HCH
Quarry (near Zaricchia)	Korostyshiv city	–	0.07 HCH
Tykhi Verby pond	Brusyliv village	0.0008 HCH	0.0007 HCH
Irsha river (unofficial swimming area), Bondaryk str.	Malyn city	0.008 HCH 0.005 DDT	0.007 HCH 0.005 DDT
The confluence of Sluch and Khomora rivers, Baranivka village	Baranivsky	0.07 HCH	0.07 HCH 0.06 DDD
Pond of Chudniv city	Chudnivsky	0.01 H	0.01 H
Floodplain of Kodnianka river	Ozerne village	–	0.01 DDD

Notes: MPC – maximum permissible concentration; HCH – hexachlorocyclohexane;
DDT – dichlorodiphenyltrichloroethane;
DDE – dichlorodiphenyldichloroethylene;
DDD – dichlorodiphenyldichloroethane; H – Heptachlor; dash – no data available.

In February 2015, an excess of DDT (0.3 mg/kg, MPC = 0.1 mg/kg) was observed in soil sampled at Romaniv village (Makarenko Street) (report No. 1–10 of February 27, 2015). In September 2017, the content of Dragon pesticide (0.29 mg/kg) exceeded MPC of 0.2 mg/kg in soil sampled at the boundary of residential development in the Romanivka village of Brusylivsky district (Centralna str., 1.25 m from the cornfield) (report No. 148–154 of 28.09.2017). The active substance of Dragon is chlorpyrifos. It belongs to organophosphate compounds. It is a modern, broad-spectrum contact insecticide against sucking and biting insects. It has high initial toxicity, blocking primarily acetylcholine esterase enzymes, which play an important role in the transmission of nerve impulses in insects.

Content of HCH, DDT, DDE, DDD, and heptachlor was measured in water bodies of the Zhytomyr region in 2018–2019 (according to the Zhytomyr Regional Laboratory Center of the Ministry of Health of Ukraine). It fluctuated in the range of 0.0007–0.01 mg/dm3, which is within MPC values (Table 2).

Table 2. Levels of pollution of water bodies with residual amounts of pesticides (mg/dm^3) in Zhytomyr region (2018–2019)

Waterbody	District	Concentration Pesticide	
		2018	2019
"Stas'ka hreblia"	Andrushivka city	0.009 HCH 0.001 DDT	0.008 HCH 0.0009 DDT
Unava river, Kvitneve village	Andruchivsky	0.009 HCH 0.001 DDD	0.009 HCH 0.0009 DDD
Pond of Popilnia village	Popilniansky	0.01 HCH 0.001 DDT	0.01 HCH 0.001 DDT
Waterbody of Khodorkiv village	Popilniansky	–	0.0008 H
Pond in Vchorayshe village	Ruzhynsky	0.001 DDD	0.0008 DDD
Lake "Skirobjednannia"	Berdychivsky	–	0.007 HCH 0.001 DDT
Irsha river	Khoroshiv city	0.006 HCH	–
Vodoyma of Guta village	Khoroshivsky	0.001 HCH	–
Lake No. 1	Korostyshivsky	0.008 HCH	–
Pond of Bezhiv village	Cherniakhivsky	0.002 HCH	–
Tykhi Verby pond	Brusyliv village	0.0008 HCH	0.0007 HCH
Irsha river (unofficial swimming area), Bondaryk str.	Malyn city	0.01 HCH 0.007 DDT	0.01 HCH 0.006 DDT
"Kaliuzha" (unofficial swimming area), Gorodyschanska str.	Malyn city	0.0008 DDE	0.0005 DDT
Pond of Malynivka village (unofficial swimming area)	Malynsky	–	0.0009 DDE
Viznia river, in Rudnia-Gorody-schenska village	Malynsky	0.0008 DDE	–
Myka river (unofficial swimming area)	Radomyshl'sky	0.008 HCH 0.0009 H	–
Teteriv river (250 m downstream of waste-water discharges)	Radomyshl'sky	0.0009 DDD	–

Waterbody	District	Concentration Pesticide	
		2018	2019
Sluch river (200 m upstream of waste-water discharges of communal enterprise "Novohrad-Volynsky VUVKH")	Novohrad-Volynsky	0.009 HCH	–
Sluch river (200 m downstream of waste-water discharges of communal enterprise "Novohrad-Volynsky VUVKH")	Novohrad-Volynsky	0.01 HCH	–
Sluch river (recreational area near Zaricchia)	Baranivka city	0.005 HCH	0.001 HCH 0.001 H
The confluence of Sluch and Khomora rivers, Markivka village	Barankivsky	0.007 HCH	0.0008 H
Pond of a brick factory	Pulyny village	0.008 HCH	0.009 HCH
Teteriv river (100 m upstream of the bridge)	Chudniv city	0.006 HCH	0.0009 DDT
Pond of Chudniv city	Chudniv city	–	0.0007 H

Notes: HCH – hexachlorocyclohexane (MPC=0.02 mg/dm^3); DDT – dichlorodiphenyltrichloroethane (MPC=0.002 mg/dm^3); DDE – dichlorodiphenyldichloroethylene (MPC=0.002 mg/dm^3); DDD – dichlorodiphenyldichloroethane (MPC=0.002 mg/dm^3); H – Heptachlor (MPC=0.001 mg/dm^3); dash – no data available.

In September 2017, the content of Dragon (0.003–0.004 mg/dm^3) and Dorpan (0.003 mg/dm^3) pesticides exceeded MPC values (0.002 mg/dm^3) in waters of private dug out wells on the Centralna and Shevchenko streets of Romanivka village, Brusylivsky district (report No. 297–301 of 28.09.2017). The active substance of Dorpan is chlorpyrifos, one of the organophosphate compounds. It is a broad-spectrum insecticide.

In August 2016, the content of Dursban pesticide (0.1 mg/kg) exceeded MPC of 0.05 mg/kg in vegetables (zucchini) produced in Yastrubna village of Brusylivsky district (report No. 44 of 4.08.2016). The active substance of Dursban is also chlorpyrifos.

3.3 Accumulation of organochlorine pesticides by freshwater bivalve mollusks

We studied the organochlorine pesticide content in soft tissues of bivalve mollusks of the species *Unio crassus* from the Perha river (Radovel' village, Olevsky district) and *Anodonta anatina* from Irsha river (Khoroshiv village, Zhytomyr region), and also in water and sediments of rivers inhabited by the mollusks. OCP enters the mollusk organisms the same as other pesticides, either through the skin, adsorption with food, or with metabolism. OCP is accumulated most intensively in the body parts of mollusks that are most exposed to the polluted environment (shell, mantle, foot, and branchia).

HCH, DDT, DDD, DDE, heptachlor were not detected in water, sediments, and tissues of bivalve mollusks by gas-liquid chromatography. Thin-layer chromatography revealed traces of Aldrin pesticide in sediments and soft mollusks (Fig. 6).

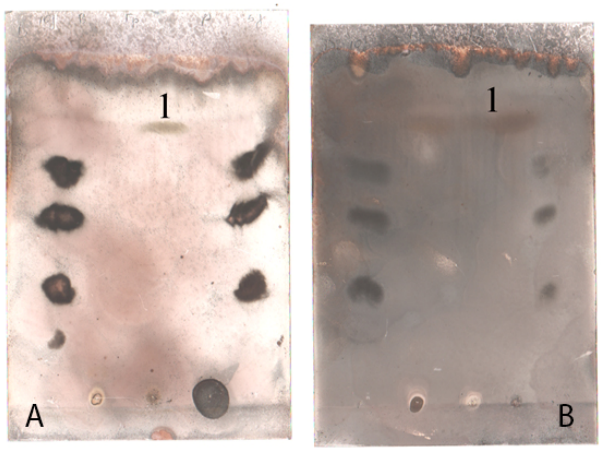

Fig. 6. Chromatogram of distribution of organochlorine pesticides on chromatogramic plate "Silufol", thin-layer chromatography (solvent system hexane, developer silver ammonia, September 2019): A – foot tissues of *Unio crassus* mollusks from the Perha river (Radovel' village, Olevsky district of Zhytomyr region); B – foot tissues of *Anodonta anatina* mollusks from Irsha river (Khoroshiv village, Zhytomyr region), 1 – trace amounts of Aldrin.

Aldrin is a pesticide, used in pest control in plant cultures and against termites. Due to its toxic effect, it is banned not only for use but also for production in Ukraine and many other countries of the world. At the same time, Aldrin reserves may be kept in numerous pesticide storages in Ukraine.

3.4 Recommendations for decreasing pesticide content in the environment

The development of scientific technologies and legislative framework is important in controlling and lessening the negative effects of pesticides on the environment. Hence, the following recommendations are topical:

- the implementation of the Stockholm Convention on Persistent Organic Pollutants in Ukraine should become a matter of national priority;
- there should be scientific studies and development concerned with the determination and monitoring of pesticides;
- system of state monitoring of environment and citizen health under the effect of pesticides should be implemented;
- the infiltration of pesticides into the environment should be limited and/or prevented;
- control should be established over economic entities that produce and sell (or otherwise realize) pesticides, and over citizens or other legal entities engaged in activities related to such pesticides;
- people of Ukraine should be informed of the dangers of pesticides;
- training programs should be developed and implemented on pesticide hazards and their implications for the life and health of humans, the environment, and of alternatives to pesticides;

- illegal circulation of pesticides in Ukraine, circulation of banned and overdue pesticides should be prevented, and areas contaminated with pesticides that are unsuitable or banned to use should be detected and cleared.

4 Conclusions

In the Zhytomyr region, nearly 392.18 t of pesticides are stored in 137 warehouses. The quality of storage containers is as follows: 39.07 t is kept in good condition; 22.43 t is kept intolerable conditions; other pesticides are stored in containers of poor quality. In 2018–2019, pesticide (HCH, DDT, DDE, DDD, heptachlor) content in soils and sediments of the Zhytomyr region was in the range of 0.0007–0.07 mg/kg, i.e. within MPC values (0.1 mg/kg). Content of HCH, DDT, DDE, DDD, heptachlor in water bodies of Zhytomyr was in the range of 0.0007–0.01 mg/dm^3, at the same time, also within MPC. In 2015, DDT content in soil (0.3 mg/kg) exceeded MPC (0.1 mg/kg) in Romaniv village; in 2017, Dragon pesticide content in soil (0.29 mg/kg) exceeded MPC (0.2 mg/kg) in Romanivka village. Also in 2017, Dragon pesticide content (0.003–0.004 mg/dm^3) and Dorpan pesticide content (0.003 mg/dm^3) exceeded MPC (0.002 mg/dm^3 and 0.002 mg/dm^3, respectively) in water samples from wells of Romanivka village. In August 2016, Dursban pesticide content (0.1 mg/kg) exceeded MPC (0.05 mg/kg) in sampled zucchini produced in Yastrubna village of Brusylivsky district, Zhytomyr region. In soft tissues of bivalve mollusks and sediments of the water bodies which they inhabit, residual traces of the organochlorine pesticide Aldrin were found.

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Monitoring of trace element content in tap water from Karachuny Reservoir, Kryvyi Rih city

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Abstract. Control of the trace element content in tap water is particularly important for large industrial regions. The estimation of Cd, Pb, Cu, As, Ni, Zn, Mn, Hg, Se and Co concentration in the tap water of Kryvyi Rih city (Karachuny Reservoir) was accomplished using electrochemical methods, the most popular methods for determining the content of trace elements in natural objects and tap water. A simple and rapid method to determine trace elements in the tap water (Kryvyi Rih city) by inversion-voltammetry has been used. The concentration of trace elements was measured by voltammetricanalyzer AVA-2 device that implements the method of inversion voltammetry on a solid rotating electrode made of carbon material. The monitoring of the trace element content in the water of the Karachuny reservoir was carried out on a monthly basis between September 2018 and August 2019. The article presents the obtained voltamperograms of some trace elements, describes content of the trace element in tap water during the year (12 data for each trace element) and analyzes the compliance of drinking water in the city of Kryvyi Rih to the standards and normative indicators of drinking water quality.

1 Introduction

The safety of water supply is one of the main factors of national security of the country. The quality of tap water is carefully monitored at the state level, as the health and life of the population depends on it [1, 2].

Drinking water is intended for human consumption to meet physiological, hygienic, household and economic needs, as well as for the production of products, so its composition according to organoleptic, microbiological, parasitological, chemical, physical and radiation indicators must meet the established hygienic requirements in the State Sanitary and Epidemiological Service of Ukraine 2.2.4-171-10 "Hygienic requirements for drinking water intended for human consumption". If the water does not meet the standards, it is cleaned and disinfected [3].

Much attention is paid to the quality of drinking water in Ukraine and abroad in the works of such scientists as I. Gushchuk, T. Kotova, I. Andrusishina, A. Serdyuk and others [4-6].

The quality of tap water is monitored with a certain frequency depending on the type of control: complete control – once a year; reduced periodic inspection – once or twice a month; reduced production control from once a month to once a day [1].

The quality of tap water is especially carefully monitored in regions with agricultural and industrial complexes, as typical problems of water quality for them are increased mineralization, hardness, and the presence of harmful impurities. All these consequences of negative anthropogenic impact on the state of water cause not only the deterioration of the taste of tap water, but first of all make it dangerous for consumption without additional purification measures.

Kryvyi Rih is one of such regions with powerful industrial complex and environmental issues. The water basin of the city has a considerable technogenic loading, which is related to the activities of the main contaminators, including the metallurgical production of "ArcelorMittal Kryviy Rih PLC", "Pivnichnyi Ore Mining and Industrial Complex PLC", "KryvbasIron-Ore Complex PLC", "HeidelbergCement Ukraine PLC" and others.

One of the important components in the composition of water that directly affects the human body are trace elements such as cadmium, plumbum, cuprum, arsenic, nickel, zinc, manganese, mercury, selenium, and cobalt. Some of them are vital microelements for living organisms, as they take an active part in biochemical processes. However, even a slight excess of their maximum permissible concentrations is very dangerous for the human body.

Plumbum has the property to accumulate in the tissues of the body, and it is manifested by the signs of damage of the central and peripheral nervous system, intestines and kidneys. It also blocks enzymes and prevents the formation of vitamins.

Arsenic is very poisonous to humans, causes widespread forms of cancer, and accumulating in the thyroid gland it becomes a cause of endemic goiter. In the case of chronic manganese poisoning, there is

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deterioration in the functioning of the central nervous system, changes in functions in the cardiovascular system, esophagus and liver.

Zinc is a very important trace element that acts as a cofactor of about 300 enzymes and it is an immunostimulator, but exceeding the permissible norms causes acute forms of poisoning. Cadmium is a very toxic element for the human body and it has the ability to accumulate and to affect the liver and kidneys, and this element is carcinogenic.

Cuprum is a part of important enzymes and proteins and it promotes growth and development of the human body, participates in hematopoiesis, and immune responses. Excessive intake of cuprum in the body causes bronchial asthma, kidney disease, liver disease, and intoxication.

Nickel is a part of some proteins, RNA and DNA, and its excess has a toxic and carcinogenic effect. Cobalt is a part of vitamin B_{12}, takes part in the processes of hematopoiesis. The excess of cobalt causes dermatitis, cardiovascular failure, and affects the respiratory system. Mercury affects the cardiovascular and nervous systems and kidneys.

Selenium is part of many biologically active compounds, participates in the regulation of metabolism, metabolism of fats, proteins and carbohydrates, as well as in oxidation-reduction processes. Selenium overdose can damage the respiratory, excretory and nervous systems [7-10].

Therefore, the significant impact of trace elements on the human body makes it important to systematically control of their content in the environment, in particular, in tap water and further purification of water from excess trace elements if it is necessary.

2 Materials and methods. Gathering samples

Voltammetry is one of the most popular methods for determining the content of trace elements in natural objects and drinking water, which is associated with the ability to detect low concentrations of elements using this method with high accuracy [11-14]. In order to determine the content of trace elements in drinking water from the Karachuny Reservoir it was used the method of inverse voltammetry.

2.1 The essence of the method of determining trace elements

The inversion-voltammetric method is based on the ability of an element to be analyzed electrochemically to accumulate on the surface or in the volume of an indicator working electrode and to dissolve in the process of anodic or cathodic polarization at a specific potential characteristic of each element.

The peak height of the element registered on the voltammogram is proportional to the mass fraction of the element in the solution.

The content of trace elements in drinking water samples is determined automatically by processing the values of the element's analytical signals on voltammograms of a series of solutions.

2.2 Device

The concentration of trace elements was measured by voltammetricanalyzer AVA-2 from Research and Development enterprise "Byrevestnik".

The AVA-2 analyzer is an electrochemical device that implements the method of inversion voltammetry on a solid rotating electrode made of carbon material.

The measuring cycle of the AVA-2 voltammetric analyzer includes four stages:
- the first stage – electrochemical regeneration of the surface of the working electrode (potential from 0 to +650 mV);
- the second stage – the electrochemical accumulation of trace elements on the surface of the working electrode (potential from 0 to -1500 mV);
- the third stage – sedation of the solution (potential from 0 to -1500 mV);
- the fourth stage is measurement, the current-potential curve is built and recorded (potential from 0 to -1500 mV).

The current-potential dependence is recorded in the form of a graph in which the position of the current peaks on the potential axis qualitatively characterizes the trace elements which is determinated (each element has its own dissolution peak). The height of the peak is proportional to the concentration of trace elements in the solution.

The AVA-2 analyzer measures the concentration of metal ions in aqueous solutions in the range, mcg/dm^3: 0,005-100 (Hg); 1-10000 (Zn); 1-200 (Pb, Cd, Cu); 1-1000 (As).

Sensitivity limit, mcg/dm^3 – 0,01 (Cd, Pb, Cu, Zn); 0,2 (As), 0,005 (Hg).

2.3 Reagents and Technique

2.3.1 Reagents

All of the used reagents were of purest quality possible (analytical grade).

Before use, distilled water was further purified by distillation with an alkaline solution of potassium permanganate.

2.3.2 Technique

The standard technique measurements of the mass concentration of toxic metal ions in drinking and surface water by inversion voltammetry was chosen for the experimental determination of the trace elements cadmium, plumbum, cuprum, arsenic, nickel, zinc, manganese, mercury, selenium and cobalt in the tap water from the Karachuny Reservoir [15].

The standard additive method was used to determine the mass concentration of element in drinking water samples. This technique measurements does not require

a calibration schedule.

The method of standard addition is based on the detection of cycles voltammperograms for the same measurement parameters of a series of three solutions:
1) background electrolyte (background);
2) sample prepared for measurements;
3) the same sample into which the solution-additive of the measured element is introduced, with a known mass concentration.

The volume of the additive solution depends on the content of the element, which is determined in the sample. It is added in such an amount that the height of the characteristic peak of the solution with the additive has to increase in 2-3 times in the sample with the added additive solution (solution 3) in comparison with the height of the peak in the experimental solution (solution 2).

The additive solution can be administered several times, but the total volume should not exceed 10% of the sample volume analyzed.

The result of three measurement cycles is a voltammogram, which determines the quantitative content of the trace element in solution.

Characteristic potential peaks for trace elements in voltammograms:
Peak potential (Zn) -1150…-800 mV
Peak potential (Cd) -600…-450 mV
Peak potential (Pb) -450…-300 mV
Peak potential (Cu) -150…-20 mV
Peak potential (Mn) -1550…-1450 mV
Peak potential (Hg) 450…650 mV
Peak potential (As) -100…300 mV
Peak potential (Ni) 1090…1180 mV

2.3.3 *Gathering samples*

The main source of tap water in Kryvyi Rih is the Karachuny Reservoir. The monitoring of the trace element content in the water from the Karachuny reservoir was carried out on a monthly from September 2018 to August 2019.

Selection, storage and handling of drinking water samples were performed in accordance with DSTU ISO 5667-6 and DSTU ISO 5667-3.

3 Results and discussion

The content of trace elements in tap water from the Karachuny Reservoir (Kryvyi Rih) was evaluated using inversion voltammetry method.

During the experiment, three consecutive measurements were made for a sample of drinking water for each element. According to the received voltammograms, the presence of a certain trace element and quantitative characteristics of its content were determined in the sample. Figures 1-2 show the voltammograms obtained for zinc and plumbum (voltage (v) with the current (a)).

The resulting voltammograms contain three curves in the coordinates voltage (V) with the current (A), which are indicated by different colors.

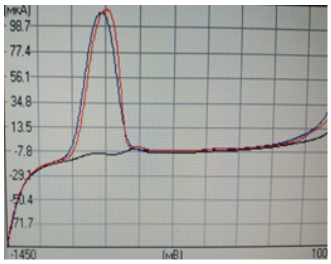

Fig. 1. Voltammogram of the trace element Zn in tap water.

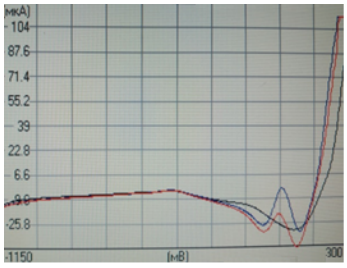

Fig. 2. Voltammogram of the trace element Pb in tap water.

The black curve reflects the value of the background solution. Red curve corresponds to the sample of the water under being tested. Blue curve corresponds to the water sample that is being investigated with the added solution-additive.

The content of trace elements in the samples of the studied tap water was calculated by automatic processing the analytical signals of the element on voltamperograms in a series of solutions. The established data of the trace elements content in tap water from the Karachuny Reservoir are presented in four tables according to the season of autumn, winter, spring and summer (Table 1–4).

Table 1. Concentrations of essential trace elements in Karachuny Reservoir (autumn 2018).

Elements	Concentrations of trace elements in mg/dm^3 ± S.D.		
	September	**October**	**November**
Mn	$2{,}3\cdot10^{-2}\pm1{,}5\cdot10^{-3}$	$2{,}6\cdot10^{-2}\pm3{,}1\cdot10^{-3}$	$2{,}1\cdot10^{-2}\pm1{,}5\cdot10^{-3}$
Cu	$6{,}8\cdot10^{-3}\pm2{,}6\cdot10^{-4}$	$8{,}1\cdot10^{-3}\pm3{,}8\cdot10^{-4}$	$7{,}8\cdot10^{-3}\pm7{,}0\cdot10^{-4}$
Zn	$3{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$3{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$3{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$
Cd	-	-	-
As	$4{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$4{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$5{,}0\cdot10^{-3}\pm1{,}0\cdot10^{-4}$
Hg	$4{,}7\cdot10^{-4}\pm5{,}6\cdot10^{-5}$	$4{,}3\cdot10^{-4}\pm5{,}6\cdot10^{-5}$	$3{,}3\cdot10^{-4}\pm5{,}6\cdot10^{-5}$
Pb	$7{,}5\cdot10^{-3}\pm3{,}5\cdot10^{-4}$	$6{,}7\cdot10^{-3}\pm5{,}7\cdot10^{-4}$	$7{,}8\cdot10^{-3}\pm3{,}1\cdot10^{-4}$
Co	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$
Ni	$7{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$6{,}3\cdot10^{-3}\pm5{,}4\cdot10^{-4}$	$6{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$
Se	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$

The results obtained in the autumn months showed a high concentration of manganese in water relative to concentration of other trace elements; the lack of detectable amounts of cadmium and low constant values for cobalt and selenium.

The trend in the distribution of trace element concentrations that was established for the autumn period repeated in the results of studies of the trace elements content in drinking water in the winter months again. And it did not change significantly in the data obtained in spring and summer studies.

Table 2. Concentrations of essential trace elements in Karachuny Reservoir (winter 2018-2019).

Ele-ments	Concentrations of trace elements in mg/dm³ ± S.D.		
	December	January	February
Mn	$1{,}6\cdot10^{-2}\pm 1{,}2\cdot10^{-3}$	$2{,}1\cdot10^{-2}\pm3{,}5\cdot10^{-3}$	$2{,}4\cdot10^{-2}\pm1{,}0\cdot10^{-3}$
Cu	$6{,}4\cdot10^{-3}\pm 6{,}0\cdot10^{-4}$	$6{,}6\cdot10^{-3}\pm3{,}0\cdot10^{-4}$	$6{,}7\cdot10^{-3}\pm8{,}5\cdot10^{-4}$
Zn	$3{,}3\cdot10^{-3}\pm 5{,}8\cdot10^{-4}$	$2{,}7\cdot10^{-3}\pm6{,}1\cdot10^{-4}$	$2{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$
Cd	-	-	-
As	$3{,}3\cdot10^{-3}\pm 5{,}8\cdot10^{-4}$	$3{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$3{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$
Hg	$2{,}7\cdot10^{-4}\pm 5{,}6\cdot10^{-5}$	$2{,}3\cdot10^{-4}\pm5{,}6\cdot10^{-5}$	$2{,}3\cdot10^{-4}\pm5{,}6\cdot10^{-5}$
Pb	$6{,}1\cdot10^{-3}\pm 2{,}0\cdot10^{-4}$	$6{,}7\cdot10^{-3}\pm2{,}0\cdot10^{-4}$	$6{,}1\cdot10^{-3}\pm2{,}0\cdot10^{-4}$
Co	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$
Ni	$6{,}3\cdot10^{-3}\pm 5{,}8\cdot10^{-4}$	$5{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$5{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$
Se	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$

Table 3. Concentrations of essential trace elements in Karachuny Reservoir (spring 2019).

Elements	Concentrations of trace elements in mg/dm³ ± S.D.		
	March	April	May
Mn	$3{,}0\cdot10^{-2}\pm1{,}5\cdot10^{-3}$	$3{,}5\cdot10^{-2}\pm1{,}2\cdot10^{-3}$	$2{,}5\cdot10^{-2}\pm2{,}1\cdot10^{-3}$
Cu	$9{,}7\cdot10^{-3}\pm2{,}0\cdot10^{-4}$	$9{,}5\cdot10^{-3}\pm5{,}3\cdot10^{-4}$	$8{,}4\cdot10^{-3}\pm4{,}2\cdot10^{-4}$
Zn	$3{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$3{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$3{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$
Cd	-	-	-
As	$3{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$3{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$3{,}0\cdot10^{-3}\pm0$
Hg	$3{,}7\cdot10^{-4}\pm5{,}8\cdot10^{-5}$	$4{,}0\cdot10^{-4}\pm1\cdot10^{-4}$	$3{,}7\cdot10^{-4}\pm5{,}8\cdot10^{-5}$
Pb	$8{,}0\cdot10^{-3}\pm4{,}6\cdot10^{-4}$	$8{,}2\cdot10^{-3}\pm3{,}0\cdot10^{-4}$	$7{,}6\cdot10^{-3}\pm6{,}2\cdot10^{-4}$
Co	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$
Ni	$7{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$6{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$5{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$
Se	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$

Table 4. Concentrations of essential trace elements in Karachuny Reservoir (summer 2019).

Elements	Concentrations of trace elements in mg/dm³ ± S.D.		
	June	July	August
Mn	$2{,}8\cdot10^{-2}\pm4{,}7\cdot10^{-3}$	$2{,}9\cdot10^{-2}\pm1{,}5\cdot10^{-3}$	$3{,}4\cdot10^{-2}\pm5{,}8\cdot10^{-3}$
Cu	$5{,}8\cdot10^{-3}\pm4{,}2\cdot10^{-4}$	$6{,}1\cdot10^{-3}\pm2{,}5\cdot10^{-4}$	$5{,}8\cdot10^{-3}\pm5{,}5\cdot10^{-4}$
Zn	$2{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$3{,}0\cdot10^{-3}\pm0$	$2{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$
Cd	-	-	-
As	$4{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$3{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$4{,}0\cdot10^{-3}\pm0$
Hg	$2{,}7\cdot10^{-4}\pm5{,}8\cdot10^{-5}$	$2{,}0\cdot10^{-4}\pm0$	$2{,}7\cdot10^{-4}\pm5{,}8\cdot10^{-5}$
Pb	$2{,}9\cdot10^{-3}\pm4{,}0\cdot10^{-4}$	$4{,}0\cdot10^{-3}\pm3{,}8\cdot10^{-4}$	$2{,}6\cdot10^{-3}\pm3{,}8\cdot10^{-4}$
Co	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$
Ni	$5{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$6{,}3\cdot10^{-3}\pm5{,}8\cdot10^{-4}$	$6{,}7\cdot10^{-3}\pm5{,}8\cdot10^{-4}$
Se	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$

In this way, monitoring of the trace element content in tap water showed that manganese, cuprum, zinc, arsenic, mercury, plumbum, nickel, cobalt and selenium were present in the tap water samples, but the concentrations of these elements were lower than the maximum levels at State Sanitary Rules and Regulations (Table 5). Cobalt and selenium were found in concentrations that were low enough for these elements. Cadmium was not in all samples or it was in quantities below the capability of the instrument used.

Figure 3 and figure 4 show the monitoring of trace elements in tap water from the Karachuny Reservoir in the period from September 2018 to August 2019.

The concentration of manganese in drinking water is the highest among all trace elements that have been studied. One of the main reasons for the increase in the manganese content in the natural waters of industrial regions is the technogenic pollution of water by industrial wastewater. This is a typical situation for industrial regions such as Krivorozhsky district. However, the concentration of manganese in the drinking water of Karachuny Reservoir does not exceed the maximum permissible concentration for this microelement (0.005 mg/dm³) and stays in the range $1{,}6\cdot10^{-2}$ – $3{,}5\cdot10^{-2}$ mg/dm³.

Table 5. The intervals of concentrations of trace elements in tap water during the autumn of 2018 – summer 2019.

Name of trace elements	Standard of the permissible limits of trace elements, mg/dm³	Concentrations of trace elements in mg/dm³	
		max	min
Mn	≤0,05 (0,5)[1],	$3{,}5\cdot10^{-2}$	$1{,}6\cdot10^{-2}$
Cu	≤1,0	$9{,}7\cdot10^{-3}$	$5{,}8\cdot10^{-3}$
Zn	≤1,0	$3{,}7\cdot10^{-3}$	$2{,}7\cdot10^{-3}$
Cd	≤0,001	-	-
As	≤0,01	$5{,}0\cdot10^{-3}$	$3{,}0\cdot10^{-3}$
Hg	≤0,0005	$4{,}7\cdot10^{-4}$	$2{,}0\cdot10^{-4}$
Pb	≤0,010	$8{,}2\cdot10^{-3}$	$2{,}6\cdot10^{-3}$
Co	≤0,1	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$
Ni	≤0,02	$7{,}3\cdot10^{-3}$	$5{,}3\cdot10^{-3}$
Se	≤0,01	$\leq5{,}0\cdot10^{-4}$	$\leq5{,}0\cdot10^{-4}$

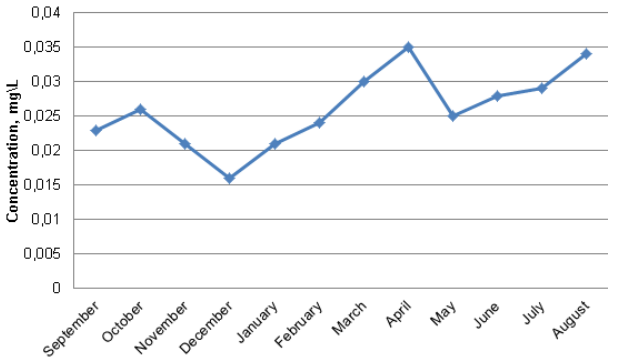

Fig. 3. Concentrations of trace element Mn in Tap water from Karachuny Reservoir.

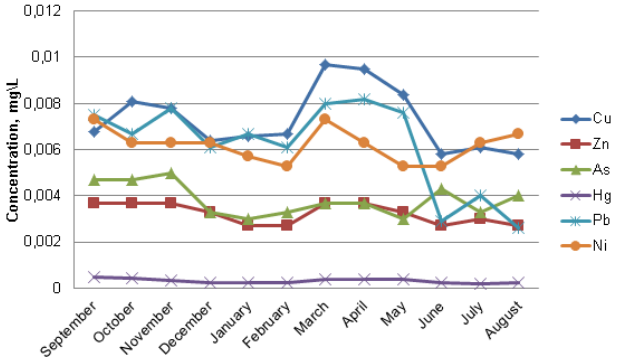

Fig. 4. Monitoring of trace element content in tap water from Karachuny Reservoir.

Changes in concentrations of trace elements Cu, Zn, As, Hg, Pb, Ni during the year are shown in Figure 4.

There are no curves that showed the content of trace elements Cd, Co and Se in drinking water which is under study on the figure 4, because the presence of cadmium

was not established by this method of study, and selenium and cobalt gave as a result low permanent data in their determination.

As shown in the figure 4, the concentration maxima for most trace elements occur in the spring season. The reason may be the ingress of polluted melt water and industrial emissions into Karachuny Reservoir during this period.

Trace elements Zn, Co and Se were founded in fairly low concentrations in drinking water. Their reduced content in water can lead to increased accumulation of iron, copper and cadmium in the human body and to frequent colds and infectious diseases [8, 16-18].

The reliability of the obtained results was verified using statistical methods of analysis with the calculation of such elementary mathematical statistics as the sample mean variance, standard deviation (Table 1-4), confidence interval, limits of confidence interval (Table 6).

Table 6. The limits of confidence interval $\dot{x}\pm\Delta\dot{x}$

*	Mn	Cu	Pb	Zn	As	Ni	Cu
09	$2{,}3\cdot10^{-2}$ ± $2{,}8\cdot10^{-3}$	$6{,}8\cdot10^{-3}$ ± $4{,}9\cdot10^{-4}$	$7{,}5\cdot10^{-3}$ ± $6{,}4\cdot10^{-4}$	$3{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$4{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$7{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$6{,}8\cdot10^{-3}$ ± $4{,}9\cdot10^{-4}$
10	$2{,}6\cdot10^{-}$ ± $5{,}6\cdot10^{-3}$	$8{,}1\cdot10^{-3}$ ± $7{,}0\cdot10^{-4}$	$6{,}7\cdot10^{-3}$ ± $1{,}0\cdot10^{-3}$	$3{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$4{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$6{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-3}$	$8{,}1\cdot10^{-3}$ ± $7{,}0\cdot10^{-4}$
11	$2{,}1\cdot10^{-2}$ ± $2{,}8\cdot10^{-3}$	$7{,}8\cdot10^{-3}$ ± $1{,}3\cdot10^{-3}$	$7{,}8\cdot10^{-3}$ ± $5{,}6\cdot10^{-4}$	$3{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$5{,}0\cdot10^{-3}$ ± $1{,}8\cdot10^{-4}$	$6{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$7{,}8\cdot10^{-3}$ ± $1{,}3\cdot10^{-3}$
12	$1{,}6\cdot10^{-2}$ ± $2{,}1\cdot10^{-3}$	$6{,}4\cdot10^{-3}$ ± $1{,}1\cdot10^{-3}$	$6{,}1\cdot10^{-3}$ ± $3{,}7\cdot10^{-4}$	$3{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$3{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$6{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$6{,}4\cdot10^{-3}$ ± $1{,}1\cdot10^{-3}$
01	$2{,}1\cdot10^{-2}$ ± $6{,}4\cdot10^{-3}$	$6{,}6\cdot10^{-3}$ ± $5{,}5\cdot10^{-4}$	$6{,}7\cdot10^{-3}$ ± $1{,}3\cdot10^{-4}$	$2{,}7\cdot10^{-3}$ ± $4{,}3\cdot10^{-4}$	$3{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$5{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$6{,}6\cdot10^{-3}$ ± $5{,}5\cdot10^{-4}$
02	$2{,}4\cdot10^{-2}$ ± $1{,}8\cdot10^{-3}$	$6{,}7\cdot10^{-3}$ ± $1{,}6\cdot10^{-4}$	$6{,}1\cdot10^{-3}$ ± $6{,}6\cdot10^{-4}$	$2{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$3{,}3\cdot10^{-3}$ ± $1{,}0\cdot10^{-4}$	$5{,}3\cdot10^{-3}$ ± $6{,}1\cdot10^{-4}$	$6{,}7\cdot10^{-3}$ ± $1{,}6\cdot10^{-3}$
03	$3{,}0\cdot10^{-2}$ ± $2{,}8\cdot10^{-3}$	$9{,}7\cdot10^{-3}$ ± $3{,}7\cdot10^{-4}$	$8{,}0\cdot10^{-3}$ ± $8{,}4\cdot10^{-4}$	$3{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$3{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$7{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-3}$	$9{,}7\cdot10^{-3}$ ± $3{,}7\cdot10^{-4}$
04	$3{,}5\cdot10^{-2}$ ± $2{,}1\cdot10^{-3}$	$9{,}5\cdot10^{-3}$ ± $9{,}7\cdot10^{-4}$	$8{,}2\cdot10^{-3}$ ± $5{,}5\cdot10^{-4}$	$3{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$3{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$6{,}3\cdot10^{-3}$ ± $3{,}1\cdot10^{-4}$	$9{,}5\cdot10^{-3}$ ± $9{,}7\cdot10^{-4}$
05	$2{,}5\cdot10^{-2}$ ± $3{,}8\cdot10^{-3}$	$8{,}4\cdot10^{-3}$ ± $7{,}6\cdot10^{-4}$	$7{,}6\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$3{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$3{,}0\cdot10^{-3}$ ± $1{,}0\cdot10^{-4}$	$6{,}3\cdot10^{-3}$ ± $3{,}1\cdot10^{-4}$	$8{,}4\cdot10^{-3}$ ± $7{,}6\cdot10^{-4}$
06	$2{,}8\cdot10^{-2}$ ± $8{,}7\cdot10^{-3}$	$5{,}8\cdot10^{-3}$ ± $7{,}6\cdot10^{-4}$	$2{,}9\cdot10^{-3}$ ± $7{,}4\cdot10^{-4}$	$2{,}7\cdot10^{-3}$ ± $6{,}0\cdot10^{-4}$	$4{,}3\cdot10^{-3}$ ± $2{,}1\cdot10^{-4}$	$5{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$5{,}8\cdot10^{-3}$ ± $7{,}6\cdot10^{-4}$
07	$2{,}9\cdot10^{-2}$ ± $2{,}8\cdot10^{-3}$	$6{,}1\cdot10^{-3}$ ± $4{,}6\cdot10^{-4}$	$4{,}0\cdot10^{-3}$ ± $7{,}0\cdot10^{-4}$	$3{,}0\cdot10^{-3}$ ± $1{,}5\cdot10^{-4}$	$3{,}3\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$6{,}3\cdot10^{-3}$ ± $3{,}8\cdot10^{-4}$	$6{,}1\cdot10^{-3}$ ± $4{,}6\cdot10^{-4}$
08	$3{,}4\cdot10^{-2}$ ± $1{,}1\cdot10^{-3}$	$5{,}8\cdot10^{-3}$ ± $8{,}0\cdot10^{-4}$	$2{,}6\cdot10^{-3}$ ± $7{,}0\cdot10^{-4}$	$2{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$4{,}0\cdot10^{-3}$ ± $7{,}0\cdot10^{-4}$	$6{,}7\cdot10^{-3}$ ± $1{,}1\cdot10^{-4}$	$5{,}8\cdot10^{-3}$ ± $1{,}0\cdot10^{-4}$

*09 – 12 months 2018 year, 01-08 months 2019 year

Statistical analysis of the monitoring results showed the absence of gross errors in the statistical sample data, all the values of the successive measurements are within the confidence interval. Therefore, the established content of trace elements in water samples can be considered close to true.

4. Conclusions

Monitoring of trace elements in the tap water from the Karachuny Reservoir showed that the content of any trace element that was selected for the study did not exceed the maximum permissible concentration during the year.

For trace elements of manganese, plumbum and cuprum, a noticeable fluctuation of the content was observed. Maximum values were fixed for manganese in April ($3{,}5\cdot10^{-2}$ mg/dm^3) and August ($3{,}4\cdot10^{-2}$ mg/dm^3); for cuprum ($9{,}7\cdot10^{-3}$ – $9{,}5\cdot10^{-3}$ mg/dm^3) and plumbum ($8{,}0\cdot10^{-3}$ – $8{,}2\cdot10^{-3}$ mg/dm^3) in March.

Minimum values were fixed for manganese in December ($1{,}6\cdot10^{-2}$ mg/dm^3); for cuprum ($5{,}8\cdot10^{-3}$ mg/dm^3) and plumbum ($2{,}6\cdot10^{-3}$ – $2{,}9\cdot10^{-3}$ mg/dm^3) in June-August.

The content of other trace elements was changing more smoothly and remained about an average value during the year. The average annual concentrations of these trace elements in water which was under study were: Zn – $3{,}24\cdot10^{-3}$ mg/dm^3; As – $3{,}87\cdot10^{-3}$ mg/dm^3; Hg – $3{,}2\cdot10^{-4}$ mg/dm^3; Ni – $6{,}28\cdot10^{-3}$ mg/dm^3.

Thus, drinking water in Kryvyi Rih in terms of the trace elements content of cadmium, plumbum, cuprum, arsenic, nickel, zinc, manganese, mercury, selenium and cobalt meet the normative requirements for the quality of drinking water and they are safe for human consumption.

However, the low content of trace elements zinc, cobalt and selenium in drinking water makes its quality worse. People should use other ways of delivering these trace elements to the body (a varied diet, vitamin complexes).

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Environmental aspects of petroleum storage in above ground tank

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Abstract. Oil pollution is a severing global environmental problem causing a number of adverse negative impacts on human health air ecosystem and eventually the natural income that is why soil, water, air pollution with petroleum hydrocarbons have become the focus of increasing public and research concern petroleum hydrocarbon contaminants in the air environment are caused by human activities when harmful or excessive quantities of substances are introduced into Earth's atmosphere. Sources of air pollution include gases such as carbon monoxide, sulfur dioxide, hydrogen sulfide, methane, the aliphatic and polycyclic aromatic hydrocarbons (PAH's) fractions of petroleum are readily evolved to air during refinery and choosing the wrong storage tanks also leak to the soil change the chemical composition of spilled toxicity and biological impacts of the oil and add great difficulties to the identification of the residual spilled oil in the impacted environment and economic cost of air pollution in illness, health care costs, lost productivity so coordination between humans to conserves natural resources for future generation.

1 Introduction

Nowadays, energy is recognized as one of the main factors to the formation and development of industrial communities. The importance of Oil and petroleum is highlighted as their basically role at human life. Egypt has major importance at this field due to great capacity of energy resources, especially oil and gas, and also special geopolitical position. On the other hand, during recent year's oil products has decreased because of growing population and increasing demand to oil products and decreasing of crude oil extraction at compare to export.

However, to achieve suitable levels of production, the use of improved technologies should be considered via introducing new facilities that treat the crude oil sulphur and nitrogen to be stored in tanks with minimal pollution to the surrounding environment, another way to save oil products and prevent the evaporation loss or leakage by construction of storage tanks according to standard codes and preferred to be stored in floating roof tanks.

Evaporation of hydrocarbons and their products from on the above ground storage tanks has been of special concern in the recent years. Emissions from storage tanks are responsible not only for a depletion of the product supply but also for contributions to atmospheric air pollution.

Storage tank of hydrocarbons are important evaporation source of volatile organic compounds (VOC) and nonorganic gases such as carbon monoxide and hydrogen sulphide, etc.

In the present investigation the methods of hydrocarbon evaporation calculation are studied and measurement of pollution. Subsequently hydrocarbon evaporation and air pollution are computed and measured from Project Consulting Group (PCG) faculty of engineering Cairo university. All necessary parameters which influence evaporation from storage tanks are measured and types of polluted gas evolved are measured. Estimation of the pollutions of oil products from storage tanks requires comprehensive information. the required data has been provided to Arabian oil pipelines company and provide oil products.

The aim of the site to collect, distribute and products are transported under pressure through a pipeline 20" length 84 km connected to Petroleum Pipeline Company which own a network of pipelines located throughout Arab Republic of Egypt, the Arabian oil pipelines company. The site are compromised of loading arm shed for charging (shipping), the oil trucker with different type of oil products like (gas oil and gasoline and kerosene) and two pumps shed. The pump shed a composed of main pumps and booster pumps are used to transportation via pipelines and storage tanks or vice versa to other oil firms using pipelines the other pump shed (B) composed of shipping pumps and two circulation pump and firefighting pump shed has diesel pumps and jockey pumps. There is measurement of chimneys of diesel pumps to monitor.

The level of SO_x and NO_x and reducing it as possible finally 12 tanks, including six fixed roof and four floating roof tanks and two double roof tanks. The tanks are contained fuel oil, Gasoline and Kerosene. Ten tanks are active and one of them is under overhaul.

The cylindrical tanks are with diameter of 44 meters

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and height of 14.64 meters. This software is designed to estimate evaporation from organic liquid storage tanks and need to specific information about tank (dimensions, construction conditions and color ...), type of liquid (chemical components and liquid temperature ...) and position of the tank (nearest city, temperature and ...) to present the evaporation from these tanks to the air.

Final reports are included monthly and annual emission for each petroleum product or combination of chemicals is stored in the tank. Evaporation rate is considered from three tanks with number one, five and six, respectively containing diesel gas oil, gasoline and kerosene. Then the observed results were used to estimate emission values from the other storage tanks.

According to software results, the estimation of annual evaporation from a gas oil tank is about 2.9 tons per year that the 2.1 tons evaporation is in operation conditions and 0.8 tons evaporation is in static conditions.

There are the other three gas oil storage tanks, so the total emission of fixed roof storage tanks containing gas oil is about 8.7 tons per year. Three storage tanks contain gasoline. Because of gasoline is very volatile and the evaporation rate is noteworthy, tanks with floating roof is used to minimize environmental pollution it's consider environmentally friendly with concern to code during construction to avoid the leakage to soil.

Annual evaporation rate of the tanks with floating roof is 33.3 ton per year. Four storage tanks were contained kerosene. These tanks have floating roof. Annual evaporation rate of the one reservoir is about 0.5 ton, so total annual evaporation of the tanks is 2 tons per year. The present estimations show annual evaporations of about 8.7, 33.3 and 2 tons of Gas oil, Gasoline and Kerosene from Arabian oil pipelines storage tanks respectively. Therefore, such evaporation can have adverse effect on the air quality of surrounding areas. In view of economical aspects such losses Implementation of simple energy savings and as color of tanks, inner condition of shell and type of primary and secondary seals can reduce evaporation Gas oil, Gasoline and Kerosene from 8.7, 33.3 & 2 ton/yr to 6.9, 9.1 & 0.4 ton/yr respectively.

We also recommend continues monitoring of storage tanks for any probable losses and minimization of polluted gas to the surrounding environment. In the future, it is suggested using cone shaped roofs while selecting among various fixed roofs.

Also, it is more logic to make use of primary and secondary seals in floating type roofs. The corrosion of inner surface of storage tanks must be controlled at minimum possible to protect soil and water supply resources if the tanks are constructed beside river or sea. It is also recommended to use white color throughout the outer surface of storage tanks.

2 Environmental management of petroleum storage tank systems

The exploration and exploitation activities of petroleum industry often causes environmental degradation that have significant impact on quality of air water soil vegetation and on health unless adequate preventive measures are planned.

To protect the natural environment, specifically air and soil and the water resources, from adverse effects that may result as a consequence of operating storage tank systems. This includes avoiding the contamination and negative ecological impacts from potential leaks and spills, and/or fires and explosions resulting from the release of petroleum products and/or allied petroleum products.

To mitigate the potential financial impacts, particularly due to spills and leaks as a result of the regular operations of storage tank systems at this industry, facilities, Community, and other buildings. That operate storage tank systems (all of the above will be referred to in this directive as institutions) to ensure that petroleum storage tank systems are operated, maintained and monitored.

3 Environmental impacts of petroleum storage in above ground tank

Petroleum industry take several steps via drilling the oil will followed by storage in tank crude oil then refinery and storage the products from the refinery process are also major contaminators of surface and ground water by leaking through the soil. The deep wells for the disposal of waste material end up in aquifers and ground water. Some of the refineries also discharge untreated waste material into the water bodies such as lakes and rivers. This means of waste disposal into the rivers affects the quality of water and the water animals. The petroleum products that find their ways into the water bodies are also highly inflammable and may cause river fires like has been the case of Cuyahoga River. Petroleum refining activities may also contaminate the soil.

Soil contamination includes the hazardous waste, oil spills, sludge from the treatment process, and coke dust. Soil contamination reduces the fertility of the soil and introduces foreign particles which may affect the growth and quality of crops.

One of the environmental impacts that may arise out of the implementation and operation of the storage tanking is oil spill and evaporization of products polluted the area each activity involves in the operation of tank farm has a potential spill risk and evaporization of different types of gases causing pollution.

3.1 Chemicals

They are also a major source of criteria air pollutants: sludge, nitrogen oxides (NO_x), carbon monoxide (CO), hydrogen sulfide (H_2S), and sulfur dioxide (SO_2). Refineries also release hydrocarbons such as natural gas (methane) and other light volatile fuels and oils.

Storage tanks also release fewer toxic hydrocarbons such as natural gas (methane) and other light volatile fuels and oils. Petroleum facilities including refinery and storage of crude oil and different products after the refinery process is a major source of pollution in areas

where they are established. The entire process are major sources of toxic air pollutants including BTEX compounds, carbon monoxide, particulate matters, and sulfur dioxide. Some of toxic chemicals released into the air are suspect cancer-causing agents and are also responsible for the development of reproductive problems, and respiratory complications. A large amount of carbon monoxide emissions traps the heat in the earth leading to climate change.

3.2 Measurements

Standards used in performing tests: Multi gas monitor IR; Particulate monitor testo. Some characteristics of the equipments used in the study are given in Table 1.

The results of Table 3 and Table 3 are applicable only for the environmental conditions during the measuring process:

– Temperature 25.3±2 C;
– Relative Humidity 24±3%.

Calibration certificate. Description Gas analyzer CO_2:

– Range: 0-5%;
– Manufacturer: GFG, Model: G460II;
– Accuracy: 2%,
– Environmental condition: 20°C.

Basis of test the instrument has been calibrated by using multi gas dilution system traceable to SI units, according to EPA method (EPA-454 / B-13-003) (see Tables 4 and 5).

Table 1. Measuring equipment.

Nomenclature	p/n	s/n	Report No.	Test method
Multi Gas monitor IR	RAE PGM 54 Gas alert micro 5 Microtector G460II	080-900996 311-020192 14031683	ENV 1903 ENV 1902 ENV 1900	MCL – Multi Gas -01 Based on EPA 600/8-97-036
Particulate monitor testo	IMR2800A Testo 330-1	D3602D27 01256553/609	163/43/2012 ENV 1900	MCL – Gas Analyzer -01 Based on EPA-emit M20, epa-m7e-m1

Table 2. Measurement of (SO_2, NO_2, NO ,CO, CO_2, VOC, Ozone, O_2) for loading arm shed for shipping the truckers.

Location name	Variables	Mean value	Expanded uncertainty	Limit as law no. (9) for year 2009 indicates as amended for the year 2011	Evaluation
Loading arm shed'	SO_2 (ppm)	0.5	±0.1	2	Accepted
	NO_2 (ppm)	0.3	±0.1	3	Accepted
	NO (ppm)	2.5	±0.3	25	Accepted
	CO (ppm)	9.0	±0.8	25	Accepted
	CO_2 (ppm)	815	±8.0	5000	Accepted
	VOC (ppm)	3.5	±0.2	N.A	N.A
	Ozone (ppm)	15.0	±1.5	120	Accepted
	O_2 (%)	21.2	±0.2	18%	Accepted
Next to tank Kersone .02	SO_2 (ppm)	0.4	±0.1	2	Accepted
	NO_2 (ppm)	0.4	±0.1	3	Accepted
	NO (ppm)	1.9	±0.3	25	N.A
	CO (ppm)	9.0	±0.7	25	Accepted
	CO_2 (ppm)	850	±9.0	5000	N.A
	VOC (ppm)	2.8	±0.3	N.A	N.A
	Ozone (ppm)	14.0	±1.2	120	Accepted
	O_2 (%)	21.2	±0.2	18%	Accepted
Next to the company fence near the suez road	SO_2 (microgm/m^3)	95.1	±10.2	350	Accepted
	NO_2 (microgm/m^3)	76.2	±8.10	300	Accepted
	NO (microgm/m^3)	57.6	±8.4	N.A	N.A
	CO (microgm/m^3)	10.4	±0.8	30	Accepted
	CO_2 (microgm/m^3)	350	±7.0	N.A	N.A
	VOC (ppm)	2.0	±0.1	N.A	N.A
	O_2 (%)	21.2	±0.3	18%	Accepted

Multi gas monitor device conduct chemical analysis on sample streams to flow from the process equipment into an analyzer sometimes conditioning the sample stream in between such as reducing pressure or changing the sample temperature is widely used for atmospheric air analysis, including applications for healthcare and environmental monitoring moreover these devices enable high throughout real time monitoring. These tests

are applied using devices such as (RAE) and (Gas alert micro 5) and (Microtector G460II) is the most advanced portable chemical detector With the flexibility of up to six gas sensors this multi-gas monitor is versatile and customizable, while delivering real-time access to instrument readings and alarm status from any location these device contains electrical pump that withdraw air sample that detect the presence of gases in area during the refinery or storage in petroleum tanks, it can detect combustible and toxic and flammable and oxygen depletion, these detectors technology are combustible gas sensor, photo ionization detector (PID), infrared sensors, electrochemical gas sensors the electrical pump withdraw air sample to be analyzed and it depend of the detection the detectors types the (PID) is a portable vapor and gas detector that detects a variety of organic compounds.

Table 3. Measured parameter: Air pollutants concentration from chimneys measurement (SO_2, NO_x, CO).

Location name	Variables	Mean value	Expanded uncertainty	Limit as law no .(9) for year 2009 indicates as amend for the year 2011	Evaluation
Generator	CO (milli gm/m^3)	120.3	±11.9	250	Accepted
	SO_x (microgm/m^3)	350.4	±24.1	1300	Accepted
	NO_x (microgm/m^3)	392.4	±31.4	500	Accepted
Firefighting diesel pump	CO (milli gm/m^3)	158.3	±13.2	250	Accepted
	SO_x (microgm/m^3)	450.4	±26.8	1300	Accepted
	NO_x (microgm/m^3)	421.4	±29.4	500	Accepted

Photo ionization occurs when an atom or molecule absorbs light of sufficient energy to cause an electron to leave and create a positive ion. The PID is comprised of an ultraviolet lamp that emits photons that are absorbed by the compound (bombardment of air sample) in an ionization chamber. Ions (atoms or molecules that have gained or lost electrons and thus have a net positive or negative charge) produced during this process are collected by electrodes.

The current generated provides a measure of the analyte concentration. Because only a small fraction of the analyte molecules are actually ionized, this method is considered nondestructive to measure volatile organic compounds and other gases in concentrations from sub parts per billion to 10 000 parts per million the other type of sensor electrochemical used for detecting oxygen and toxic gases.

More specifically, they measure the concentration of a specific gas within an external circuit. This is done by method of oxidation or reduction reactions. These reactions generate the positive or negative current flow through said external circuit the third type Microtector G460II.

Use IR sensor for (O_2, H_2S, CO, CO_2 and combustible gases, in particular, NO_2, SO_2 and a variety of other gases) and combustible gases (LEL and 100% vol.) for a non-toxic atmosphere.

Measures trace gases by determining the absorption of an emitted infrared light source through a certain air sample. The report expanded uncertainty values are based on a standard uncertainty multiplied by a coverage factor (K=2), providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with (ukas) requirements.

The standards used to perform this test are traceable to standard defined and maintains and disseminated by the (NIS) or other international standards organization or have been derived from accepted values of natural physical constants.

The result shown in this report is applicable only for the environmental conditions during the test itself.

Table 4. Calibration result Gas analyzer CO_2 G460II.

Applied values CO_2, %	Reading values CO_2, %	Error CO_2, %
0	0	0
0.5	0.51	0.01
1	1.05	0.05
2	2.3	0.3
3	3.3	0.3

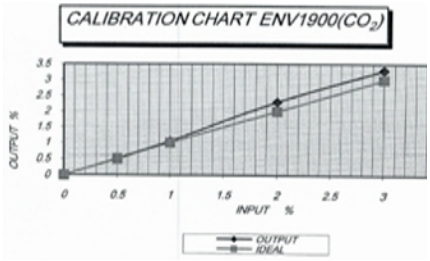

Fig. 1. Calibration chart of Gas analyzer CO_2 G460II.

The calculated uncertainty = ±2.839%.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor.

Description gas analyzer (SO_2):

– Range 0-20 ppm;
– Manufacturer: CFG, Model G460II;
– Accuracy: 2%;
– Temperature 20°C;

– Humidity: 62.9%.

Basis of test: the instrument has been calibrated by using multi gas dilution system traceable to SI units and according to EPA method (EPA-454/B-13-003).

Table 5. Calibration result Gas analyzer SO_2 G460II

Applied values SO_2 (ppm)	Reading values SO_2 (ppm)	Error SO_2 ppm
0	0	0
3	3	0
5	5	0
8	8.1	0.1
10	10.1	0.1

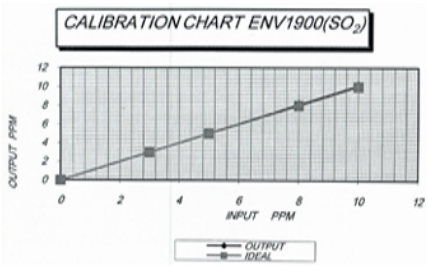

Fig. 2. Calibration chart of Gas analyzer SO_2 G460II.

The calculated uncertainly= ±2.83%.

The reported expanded uncertainly is based on standard uncertainly multiplied by a coverage factor K=2 providing a level of approximately 95%.

From the results of previous measurements, it is clear that all the results of measurements comply with environmental law no. (9) of 2009 and the amendments for the year 2011.

4 Results and discussion

To decrease pollution potential, place tanks within a secondary containment structure consisting of a dike and a pad. All piping should be above ground within the dike or may go over the dike wall.

However, if it goes over the dike wall, it must be placed below the ground and within 10 feet of the dike wall. Above-ground piping must be made of steel and coated to prevent corrosion. Any below-ground piping may be either steel or fiberglass, but the steel piping must be coated and catholically protected, floating roof tank are preferred to prevent vaporization of gases which are responsible for pollution, spill protection usually consists of a catch basin for collecting spills when the tank is filled. Overfill protection is a warning device such as a buzzer or a prevention device such as an automatic shutoff. These precautions can prevent a number of small releases over time from polluting ground water.

Installation of flame arrestor and breathings valves to guarantee the safety of the tanks to avoid petroleum fires which lead the pollution to the environment with different kind of gases and toxic gases to control the air pollution and treatment of crude oil during the refinery process to eliminate the inorganic and organic contaminant especially sulfur to reduce the air pollution, monitoring the storage tanks with multi gas detector to evaluate the percentage of harmful gases and polluted gases to atmospheric air.

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Modern environmental technologies of healthy soils contaminated by heavy metals and radionuclides

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Abstract. Object of research: to systematize (taking into account the possible consequences to biosphere) the known technologies for ecological restoration of soils contaminated by heavy metals and radionuclides. Only a healing technology should be recognized as one possible methodology for solving any soil problems. For soils contaminated by heavy metals and radionuclides healing patterns is conceptually ordered into the following levels: mission, strategy, technology. The mission of healthy soil should be aimed at maintaining the chemical elements content within the optimum interval. The strategy of healthy soil involves the regulation of individual elements content in the soil. Ex-situ a soil healing technology is implemented outside the original pollution site. In-situ, a soil healing technology is carried out directly on the original pollution site. Excavation of the contaminated soil layer is the first stage for ex-situ soil restoration. In the future it will be possible: 1) storage of contaminated soil at special landfills, 2) treatment of contaminated soil at a special reactor. All technologies for in-situ healthy of heavy metals contaminated soils can be ordered as: 1) localization, 2) deconcentration, 3) inactivation, 4) extraction.

1 Introduction

Soil, as an indispensable component of the biosphere, plays a crucial role in solving the problem of Human & Nature interaction. It is the soil, as well as its unique ecological properties that shape the conditions and provide the means of existence for human civilization [8, 20, 30, 34, 43].

The large accumulation of pollutants in soils is the most urgent task for modern soil science. Among the soil pollutants, heavy metals and radionuclides are the most dangerous to human health. On the 21st century, the total area of contaminated land by these political agents is estimated in millions of hectares. In soil the heavy metals' half-life is hundreds and thousands of years, and the radionuclides' half-life is tens and hundreds of thousands of years [21, 24, 28, 38, 44]. That's why, multiple studies were performed to technology development for cleaning the soil, contaminated with heavy metals and radionuclides. However, the proposed contaminated soil cleaning technologies have a clearly anthropocentric character [1, 4, 23, 26, 45].

At the same time, possible consequences for living organisms and soil from a new technology for a contaminated land restoration introduction were left without due attention [3, 18, 24, 36, 46].

Object of research: to systematize (taking into account the possible consequences to biosphere) the known technologies for ecological restoration of soils contaminated by heavy metals and radionuclides.

2 Materials and methods

As the materials of this work were used: 1) own long-term research results; 2) modern scientific publications, which contain: a) real achievements in soil ecology / biospherology, b) data on successful technologies for restoration / purification / rehabilitation of soils contaminated by heavy metals and radionuclides.

In this work, research methods such as analysis and synthesis, induction and deduction, analogy and formalization, abstraction and concretization, classification and modeling were used.

3 Results and discussion

We believe that the concept of sustainable development is the main paradigm for modern soil science. However, for the successful implementation of this concept in soil science, soil must be considered as: 1) the object of production, 2) a component of the human habitat, 3) the functional of the biosphere.

3.1 Principal model of the healthy soil

We believe that, the known and tested technologies for restoration of contaminated soil have exclusively

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anthropocentric character. Since in most cases, they are aimed at solving the problems of society – the negative consequences for humans of the excessive pollutants content in soils to reduce. Whereas, modern technologies for restoration of contaminated soil should be based solely on the principles of pedosphere.

Therefore, the one possible methodology for solving any soil problem should be recognized only as a healing technology. As applied to heavy metals and radionuclides, soil improvement should include 1) elimination of negative consequences for the biosphere and humanity from the presence of these pollutants in soils, 2) unconditional preservation of soil functioning parameters within the limits of naturally acceptable norms. It is important to clarify that in solving any environmental problem, ignoring the conservation of soil health is possible only in exceptional cases (for example, the presence of a direct threat to human health). However, after eliminating the negative consequences of the soil pollutants action, measures are necessary for a soil properties and soil health regeneration.

In our opinion [27, 28, 29, 30, 48] for soils contaminated by heavy metals and radionuclides healing pattern is ordered conceptually into the following levels: mission, strategy, technology. The mission of healthy soil should be aimed at maintaining the chemical elements content within the optimum interval. The strategy of healthy soil involves the regulation of individual elements content in the soil. With a lack of certain metals (as nutrients), it is advisable to add metals to the soil (as fertilizer). With excessive content of heavy metals and radionuclides in the soil, it is necessary to eliminate and / or limit their negative impact on soil, biota, farm animals and humans. It must be emphasized that soil healing technologies involve of two measures implementation, which vary in location. In the first case (ex situ) a soil healing technology are implemented outside the original pollution site. In the second case (in situ), a soil healing technology are carried out directly on the original pollution site.

3.2 Ex situ healthy of contaminated soil

Excavation of the contaminated soil layer is the first stage for ex-situ soil restoration (Fig. 1). For this purpose, only the upper soil layers (0-5 cm, maximum 0-20 cm) are usually removed, since in these soil layers a prohibitive heavy metals / radionuclide content was usually [2, 5, 7, 11, 49].

In the future, two systems of activities can be implemented. The first technology is the storage of contaminated soil at special landfills. The second technology is the treatment of contaminated soil at a special reactor.

Storage of contaminated soil can be performed: a) with preliminary treatment by special reagents that reduce the mobility of pollutants in the soil (lime, phosphogypsum, carbonates), b) without preliminary treatment [6, 9, 15, 19, 47].

The technology of storing contaminated soil, as a method of healing contaminated lands, has numerous applications in world practice. However, this technique does not solve the problem of the presence of pollutants in the soil, but only "preserves it." That is why the widespread use of the storing heavy metals contaminated soil method is inappropriate. However, exceptions are possible – in limited areas, which are of very great importance. While for radionuclides, most likely this is the most likely way to improve excessively contaminated soil.

As we noted earlier, the second technology is the treatment of contaminated soil at a special reactor. In our case, only metals can be removed, therefore this method is called "demetalization". For this purpose, it was used [30]: 1) physical (hydrocyclonation, separation by density gradient, sonication), 2) chemical (washing with reagents, flotation), 3) physicochemical (electrochemical leaching), 4) biological (microleaching) techniques for contaminated soil demetallization (Fig. 1).

According to scientific literature date [10, 13, 25, 49, 51], soil demetallization technologies are characterized by: 1) a high degree of metal recovery (in some cases up to 95-95%); 2) low productivity of installations (from 10 to 300 tons of soil per day); 3) the high cost of cleaning (100-450 USD per 1 m3 of soil). It is also necessary to note that a soil that has undergone a full treatment cycle often loses a number of its leading properties. Therefore, after contaminated soil demetallization it is very necessary to apply techniques to restore soil fertility. Only after this, the cleared soil can be returned to its former place of residence.

3.3 In situ healthy of contaminated soil

3.3.1 Environmental healthy of metals' contaminated soil

In our opinion, all possible technologies for in-situ healthy of heavy metals contaminated soils can be ordered as: 1) localization, 2) deconcentration, 3) inactivation, 4) extraction (Fig. 2).

Localization is a technology that involves spatial limitation to increase the area of pollution. Localization has three directions: 1) phytolocalization, 2) technolocalization, 3) chemolocalization [30, 50].

Phytolocalization involves limiting the distribution of metals as a result of creating an artificial vegetation cover: grassy or woody. At the same time, the success of phytolocalization is determined by the combined action of two factors: the edaphic conditions of the contaminated area, and the selection of plants. To increase the efficiency of phytolocalization, it is recommended to use several ameliorants.

Technolocalization involves limiting the spread of metals from contaminated areas using mechanical barriers. At the same time, depending on the location and technology of creating such barriers, there are: mulching and the formation of techno-curtains.

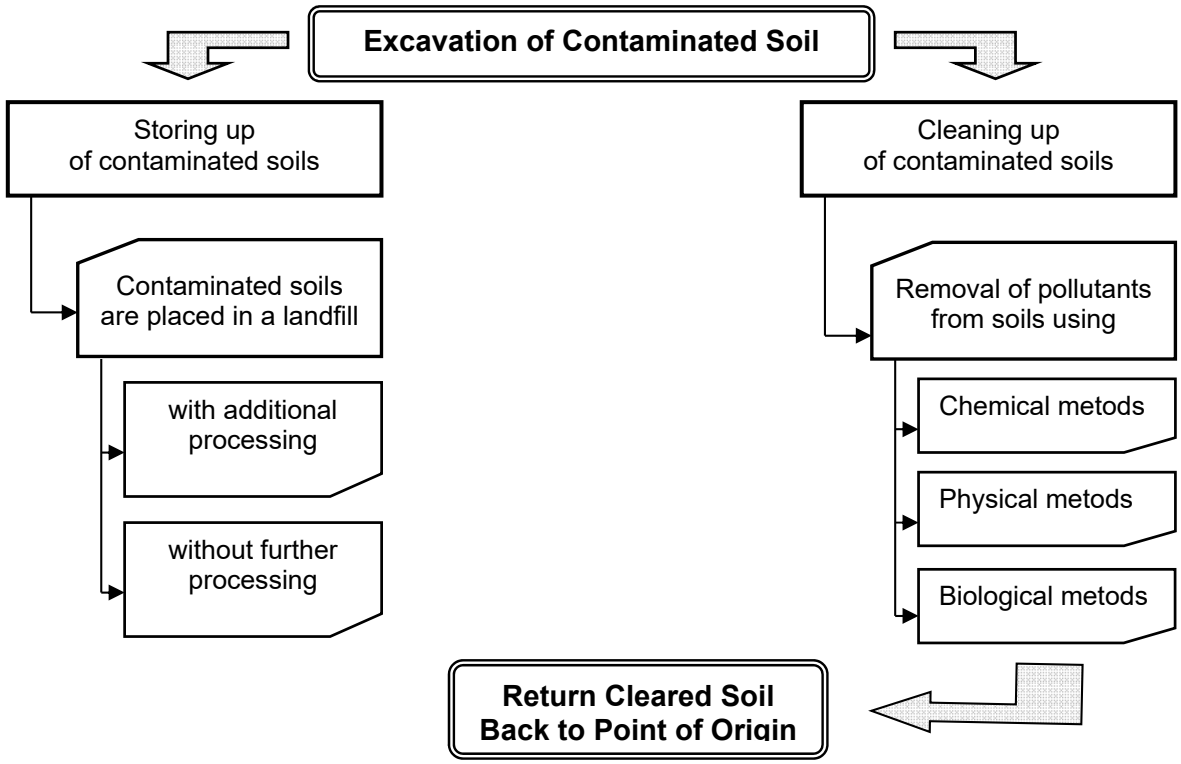

Fig. 1. Concept pattern "*ex situ* healthy soils contaminated by heavy metals and radionuclides".

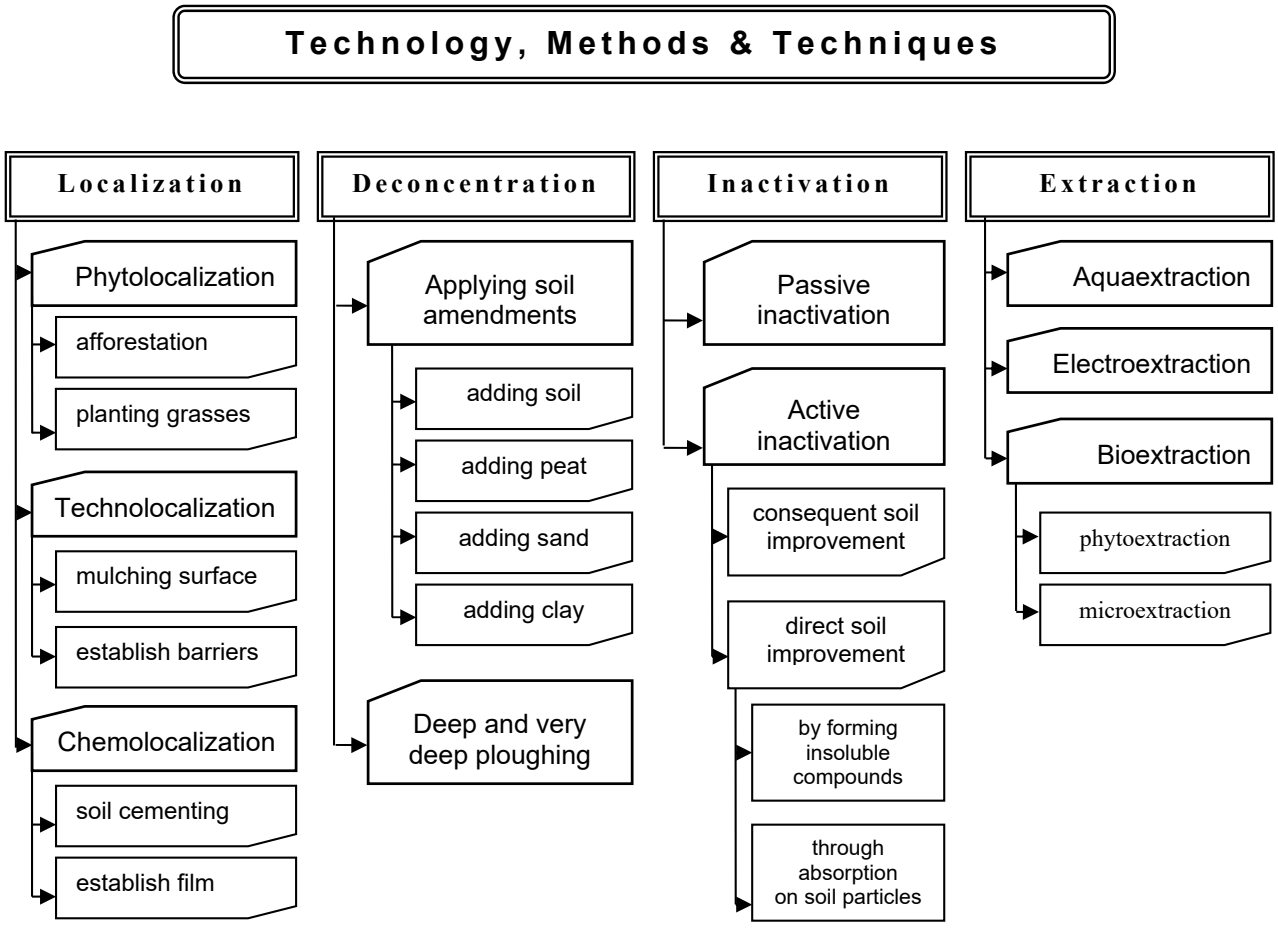

Fig. 2. Concept pattern "In situ healthy soils contaminated by heavy metals".

Chemolocalization involves limiting the distribution of metals from contaminated territory, with the help of obstacles formed as a result of chemical reactions. Depending on the place of the reaction and the chemism of the formation of such barriers, chemolocalization is divided into: subsurface cementing and the creation of a protective film. The technology of subsurface cementing involves the introduction of special reagents into the soil, which determines the chemical bonding of pollutants and the formation of special granules. The technology for creating a protective film involves applying special substances to the surface of contaminated soil, which, as a result of chemical interaction with each other, as well as with soil components, form a stable coating. Such a coating, isolating the contaminated soil surface from the action of wind and precipitation, prevents the emission of pollutants as a result of erosion [30].

Deconcentration is a technology that involves mixing the contaminated soil horizon with uncontaminated soil layers and / or loose soil-like substrates. As a result, there is a decrease in the concentration of metals in soils. In practice, two methods of deconcentration of metals in soils are possible: 1) application of soil-like substrates, 2) deep plowing (Fig. 2).

Inactivation is a technology that involves the transfer of metals from the active (liquid phase of the soil) to inactive (solid phase of the soil). Inactivation of metals is divided into passive and active (Fig. 2).

The principle of passive inactivation of metals is to restore the natural fertility of the soil. The principle of active inactivation is the direct transition of metals to inactive forms due to: 1) the occurrence of certain pedogeochemical reactions, 2) the creation of special pedogeochemical conditions. In the first case, technologies of active direct inactivation of metals are implemented. The second implements technologies of active indirect inactivation of metals [12, 14, 32, 51].

It is promising to use: 1) clay content of a substance, 2) humic substances, 3) phosphate compounds, 4) calcareous materials, 5) industrial waste products, 6) specially synthesized substances for active direct inactivation of metals in soils. For active indirect inactivation of metals in soils, it is promising to use: 1) organic fertilizers (manure, peat, compost), 2) mineral fertilizers, 3) chemical reclamation reagents (lime, gypsum).

Extraction – those technologies that are aimed at the complete extraction of metals from the soil. The extraction of metals from the soil can be realized as: 1) aqua extraction, 2) electroextraction and 3) bioextraction (Fig. 2).

Aqua-extraction involves translocation of metals from contaminated soil layers beyond the soil profile using water and / or aqueous solutions of special reagents.

Electroextraction involves the extraction of metals from the soil due to the action of chemical reactions that obey electrokinetic's laws. Fundamentally, this technology is based on the directional movement of metals in the presence of an external electric field.

Bioextraction is based on the ability of living organisms in the process of their life to extract from the soil and accumulate metals in their bodies. As a result, there is a process of translocation of anthropogenic metals in the direction of "soil – living organisms". Bioextraction should be divided into: phytoextraction, zooextraction, microextraction and fungiextraction. However, in practice, bioextraction is represented mainly by two technologies: phytoextraction and microbextraction.

Phytoextraction is based on the natural ability of plants to absorb from the environment and accumulate metals in their tissues. As a result, directional translocation of metals from the soil to the aboveground phytomass occurs, which eventually collects and moves away from the territory. The result – the concentration of metals in the soil is gradually reduced to the required level. Studies of the last 20-25 years have shown that about 400 plant species from 45 families can be considered as metal hyperaccumulators [29, 30, 42, 43].

An innovative way to increase the efficiency of phytoextraction of metals from soils is the use of chemicals that significantly increase the flow of metals in the Soil – Plants system. Such substances are called "activators" or "effectors" for the phytoextraction of metals from soils [4, 10, 30].

In the global perspective, it is possible to use phytoextractors enriched with biomass metals as phytogenic raw materials for the enrichment industry. Therefore, in the future, a wide-scale application of phyto-ore and phyto-mining technologies is possible.

Microextraction is a technology that is based on the use of the natural abilities of microorganisms as metal acceptors.

In this regard, it is assumed that there will be a targeted extraction of pollutants from the soil with their subsequent accumulation in microorganisms.

Microorganisms are able to extract metals from the soil as a result of reactions: adsorption, precipitation and oxidation; changes in the valence of metals, extracellular chemical deposition, volatilization; oxidation, immobilization and binding; binding, changes in the valence of metals, volatilization, extracellular chemical deposition and symbiosis with plants [6, 13, 43, 47, 51].

3.3.2 Environmental healthy of radionuclides' contaminated soil

The radiation background following the Chernobyl nuclear power plant (ChNPP) accident in April 1986 was determined by 21 radionuclides. Most of them fell out with fine carbon particles (with adsorbed metal atoms condensation forms), as well as in the form of fuel particles. The greatest danger to living organisms was represented by a biologically active radionuclides group: ^{131}I; ^{90}Sr; ^{137}Cs; $^{238,239\ 240}Pu$; ^{141}Ce; ^{144}Pr; $^{103,106}Ru$; ^{95}Zr; ^{95}Nb. Heterogeneous in their dosimetric characteristics, these radionuclides have one thing in common: most of them are counterparts, analogues of chemical elements that perform important biological functions in living organisms and plants [16, 17, 22].

Radioisotopes with a long half-life are especially dangerous. This group includes such surface pollutants

as ^{90}Sr, ^{137}Cs, ^{241}Am and all plutonium isotopes. ^{137}Cs and ^{90}Sr pose the greatest danger to humans, animals and plants. They are easily integrated into trophic chains and are sources of internal and external irradiation of organisms. It is known that ^{90}Sr. is an analogue of Ca and ^{137}Cs is K. They are well soluble in water, easily absorbed by soil and are biologically mobile in agricultural chains, and have a long half-life ($T_{½}(^{137}Cs)$ = 30,7 years; $T_{½}(^{90}Sr)$ = 28,1 years) [2, 7, 9].

^{137}Cs is one of the major dose-forming radionuclides among fission products. An important feature of this isotope is the ability, along with exchange binding, to solid phase soil sorption (fixation), in particular, entry into interpacket spaces and fixation of Cs^+ ions by a crystal lattice of some secondary clay minerals. Firmly fixed Cs^+ ions are less likely to be converted into soil solution and therefore become less accessible to most crops. Unlike ^{137}Cs, the main mechanism of absorption of ^{90}Sr by the solid phase of soil is ion exchange. The sorption of this radionuclide by the solid phase of the main soil types depends on the presence of macroconcentrations of other cations and anions in the soil solution [11, 15, 22, 36].

According to N. V. Timofeev-Resovsky [39, 40], the availability of radionuclides for plants depends primarily on soil properties and their behavior in soil (soil chemistry of radionuclides). The absorption of radionuclides by soil is determined by their distribution between the solid phase of the soil and the soil solution and is carried out at the expense of the processes of sorption – desorption, precipitation-dissolution of difficult-soluble compounds and coagulation – peptization of colloidal particles. The formation and dissolution of precipitation depends on the ionic composition, pH, Eh of the soil solution, and the presence of organic and inorganic acids. Adsorption of radionuclides from soil solution by solid phase of soil is closely related to the properties of mineral, organic and organomineral colloids [33, 35].

The behavior of cesium isotopes (^{134}Cs and ^{137}Cs) is determined by the fact that they are radioisotopes of an alkaline element having an oxidation degree of only +1 in any component of the natural environment. One of the most important features of these isotopes is the ability to invariably adsorb (fix) the solid phase of the soil, leading to a decrease in soil motility and a decrease in plant accumulation. The combination of soil-chemical (crystal-chemical) reactions leading to a decrease in the mobility of radionuclides in the soil due to their entry into the interpackage spaces of secondary minerals is commonly called “aging” [31, 37, 41].

The absorption and strength of ^{137}Cs by soil are significantly influenced by the content of K^+ ions and the presence of other competing cations in the soil solution. Thus, substitution in the soil-absorbing soil complex of all exchange cations by K^+ or Ca^{2+} ions markedly increases the sorption of Cs^+ ions. By reducing the influence on the sorption of the radionuclide by the solid phase of the soil, the cations competing in the soil solution can be arranged in the following order: $Cs^+ > Rb^+ > NH_4^+ > K^+ > Na^+ > Ca^{2+} > > Mg^{2+} > Sr^{2+}$.

Unlike ^{137}Cs, the main and only mechanism for the absorption of ^{90}Sr is ion exchange. The behavior of this isotope in soil is determined by the behavior of an isotope carrier (stable Sr) and a chemical analogue (stable Ca).

Absorption of this radionuclide by the soil solid phase is closely related to the concentration in the soil solution of other cations. The content of exchangeable Ca in the soil has a major influence on the uptake of ^{90}Sr into agricultural plants, and the cations on their competitive ability to influence the absorption of a given radionuclide can be arranged in the following order: $Al^{3+} > Fe^{3+} > Ba^{2+} > Ca^{2+} = Sr^{2+} > Mg^{2+} > Cs^+ = K^+ > NH_4^+ > Na^+$.

When large quantities of Ca^{2+} cations are introduced into the soil, as a rule, there is a sharp decrease in the ^{90}Sr / Ca ratio in the soil solution, which leads to a sharp decrease in the flow of the first to the plants.

As noted by several authors, the concentration in soil solution of anions PO_4^{3-}, SO_4^{2-}, CO_3^{2-} also influences the behavior of radionuclides in the system “soil-plant”. Thus, the availability of ^{90}Sr decreases due to the increase in soil solution concentration of PO_4^{3-} anions as a result of the formation of $Sr_3(PO_4)_2$ and $SrHPO_4$ compounds inaccessible to plants.

Many domestic and foreign researchers believe that the main role in the behavior of radionuclides is played by the agrochemical properties of soils. At present, about ten basic parameters are distinguished from all the physicochemical characteristics of soils, which affect the mobility and accessibility of ^{137}Cs and ^{90}Sr, which in increasing importance can be placed in the following order: > organic matter content> exchange contents K, Ca, Mg> cation exchange capacity> pH.

According to several scientists, the main mechanism of radionuclide movement along the soil profile is the process of diffusion from the zone of high concentration to the zone with lower concentration, transfer in a stream with a fine fraction of soil and transfer in the composition of soluble organic compounds (fulvates and humates) [16, 21, 28, 38].

A significant difference in the mobility of ^{137}Cs and ^{90}Sr in the soil should be noted. As ^{137}Cs can be fixed by mineral components of the soil, their movement along the soil profile is characterized by transfer with fine particles of the soil in a fixed state, whereas 10-40% ^{90}Sr is bound by the humates of the soil absorbing complex (humic, humatomyelin, and especially fusional forms). Bonding with soil organic matter explains the greater mobility in soils of ^{90}Sr compared to ^{137}Cs. A confirmation of the faster ^{90}Sr pre-vision is the increase in the proportion of its exchange forms as it sinks, which is not characteristic of ^{137}Cs. For most radionuclides, increasing the humus content in the soil provides a steady decrease in the size of their transition to the plant. According to G. A. Sokolik with colleagues the availability of ^{90}Sr for plants in ionic form is 2-4 times higher than from organomineral complexes. The authors found that the ^{137}Cs transition from humates was 1.3-1.5 and ^{90}Sr 2-2.5 times lower than from fulvates.

According to some scientists [14, 33, 35], the increase of humus content in sod-podzolic sandy

loam soils from the minimum (1,0-1,5%) to the optimum (2.0-3.0%) was accompanied by a decrease of 1.5 times the ^{90}Sr and 2-5 times ^{137}Cs in the crop of perennial cereals.

The power and ash content of the peat layer are important factors influencing the intake of radionuclides into the crop of perennial grasses on peat-bog soils. It has been established that the cultivation of peat soils leads to an increase in the mineralization of peat mass (an increase in the ash content) and to a decrease in the radionuclide input into the grass.

In the period from 1986 to 1992, a stable positive balance of calcium, potassium and organic matter in soils was maintained in the majority of Belarusian farms located in the contaminated radionuclide zone. This, along with other measures, contributed to a significant reduction in the transition of radionuclides to products.

Since 1993, due to economic difficulties, the volume of soil fertility maintenance has declined sharply. This raises the fear of a decline in the rate of improvement of crop production, and in some places exceeds the permissible levels of radionuclide content in forage crops. In some cases, maintaining a higher humus content in the soil (3,1-3,5%) may be justified for the radioactive contamination zone in order to further reduce the radionuclide intake in the presence of cheap sources of organic matter (straw, green fertilizers) [31].

The particle size distribution of soils largely determines their absorption capacity and the sorption processes of radionuclides occurring therein. The sorption capacity of soils is directly proportional to the degree of dispersion of the soil particles. The soils of heavy granulometric composition have a larger number of fine fractions than light soils.

K. K. Gedroyts [14] pointed out that the silt fraction of the soil plays a major role in the exchange capacity of soils. The role of larger mechanical soil elements in the physicochemical absorption is small. The soil fraction larger than 0,001 mm has an absorption capacity from 0,12 to 13,4 mg-eq. per 100 g soil. Particle fraction less than 0.001 mm has an absorption capacity from 20,6 to 107,4 mg-eq. per 100 g soil.

Soils containing a large number of fine particles (smaller than 0,001 mm in size) are characterized by a high absorption capacity. As the particle size decreases, the content of silicon oxide decreases, the amount of one and a half oxides of iron and aluminum increases, and the content of humus and exchange cations of calcium, magnesium and potassium increases (the latter is especially important for radionuclide sorption processes). The smallest dust and silty particles have the highest content of organic matter.

With the reduction of the size of the soil fractions, the strength of their ^{90}Sr and ^{137}Cs strength increases. For example, in the fine sand fraction of sod-podzolic soil and chernozem, 37-45% of the absorbed amount of cesium remains not displaced after three treatments by ammonium chloride. This indicates that the mineral part of the soil particles is of great importance in the sorption of ^{137}Cs.

Dusty fractions have an even greater ability to fix cesium radioactive isotope than sandy ones. Thus, in the silt fraction of soils, the highest amount of ^{137}Cs remains, which are not displaced into the ammonium chloride solution after repeated treatment. From a practical point of view, it is interesting to monitor the distribution of radionuclides by the fractions of contaminated soils. The bulk of ^{90}Sr is concentrated in silty and clayey soil fractions of different types. The clay fraction (less than 0,01 mm) accumulates from 50 to 85% ^{90}Sr of the total soil content. It should be borne in mind that the proportion of different fractions in the particle size distribution of soils is not the same. In addition, differences in the properties of granulometric elements of varying degrees of dispersion are explained by the features of the mineralogical composition. In the clayey and colloidal fractions of soils secondary minerals – groups of montmorillonites, vermiculite – predominate. All of them (unlike primary minerals) are characterized by high absorption capacity, including for radionuclides.

According to some researchers, the sorption of radionuclides by soil depends to a large extent on its mineralogical composition. Thus, 98-99% of the ^{137}Cs concentration in the soil is sorbed by minerals of the montmorillonite group, mica and hydromica. By the ability to absorb and firmly retain ^{137}Cs minerals can be arranged in descending order: ascanite, hydroflogopite, phlogopite gumbrin, vermiculite, bentonite, kaolinite, vivianite, muscovite.

Secondary clay minerals can also be sorbed up to 99% of ^{90}Sr content in soil. For example, from soil solutions montmorillonite group minerals were absorbed from 92,1 % to 99,9 % of ^{90}Sr content in soil. The kaolinite group minerals were absorbed from 40 % to 68 % of ^{90}Sr content in soil. The mica minerals were absorbed from 71 % to 87 % of ^{90}Sr content in soil. The minerals of the calcite, feldspar and quartz groups were absorbed 10 to 50% of ^{90}Sr content in soil. Preferably, this radionuclide is sorbed by such minerals as ascanite, bentonite, vermiculite, phlogopite igumbrite. To a much lesser extent, it is sorbed by hydro muscovite and hydrogetite.

In our opinion [27], differences in the completeness of sorption of radionuclides from the soil by different minerals are due, first of all, to the different structure of their crystal lattice. Thus, the minerals of the montmorillonite group (ascanite, gumbrine), as well as the minerals of the mica and hydromica group, due to the structure of the crystalline lattice, have intramicellular absorption (cations entering the crystalline lattice). Therefore, they more fully absorb the micro-amounts of radionuclides from the soil. In addition, these minerals more firmly fix them in the absorbed state compared to the minerals of other groups (kaolinite group). These minerals are characterized by extracellular absorption (absorption of cations on the surface of crystalline lattice layers).

Therefore, the stronger anchoring of ^{137}Cs with soils compared to ^{90}Sr is due, first of all, to the strong sorption of this radionuclide by the mineral part, especially by the highly dispersed fractions containing the minerals of the montmorillonite group and the group of hydro-mica.

The ^{137}Cs-free carrier can be absorbed by the soil by sorption of the element on the surface of the three-layer

minerals. However, it cannot be substituted for hydrogen, sodium, calcium, magnesium or barium ions. Because, these ions not a component of the soil crystal lattice.

^{137}Cs micro-quantities in soil can only be partially replaced by potassium, ammonium and stable cesium. It was also found that the decrease in the availability of ^{137}Cs under the influence of the flagopite and the hydroflagopite is due not only to its strong fixation in the crystal lattice, but also to the content of mobile potassium in this mica.

It should be noted that among the lands contaminated by radionuclides of the Republic of Belarus and Ukraine, more than half are soils of light granulometric composition. Therefore, these soils are characterized by low absorption capacity, low content of humus and secondary clay minerals, increased hydromorphicity and high rates of transition of radioactive substances to agricultural crops. These factors make it difficult to obtain "pure" crop and livestock products (containing radionuclides within the limits of radiation safety).

According to the degree of permeability of radionuclides on the soil profile of different granulometric composition, the following series can be constructed as it decreases: sands, sandy loam, and loam. According to the researchers, the determining factor for the radionuclides from soil to plants is the properties of the soil absorbing complex. The strength of sorption of radionuclides in soil is higher; the greater is its cation exchange capacity and the sum of exchange bases. Strong sorption of ^{137}Cs and high availability of 90Sr at root admission were noted. Some scientists play a significant role in the absorption of radionuclides (^{134}Cs, ^{137}Cs, ^{85}Sr, ^{90}Sr) by soil parameters such as temperature, pH, and the ratio of liquid and solid phases of soil solution.

It was found that the concentration of ^{90}Sr in meadow plants with decreasing pH and exchange calcium in alluvial soil decreased. Increasing the fraction of silty fraction in the humus-accumulative horizon above the specified soil type decreased the concentration of both ^{137}Cs and ^{90}Sr.

According to many researchers [33, 35], pH is the leading soil factor that determines the mobility and availability of radionuclides. Thus, humic and other low molecular weight acids limit the mobility of radioactive elements. Therefore, the absorption strength of radionuclides by the soil absorption complex, on the contrary, is weakened. The reason due to the formation of negatively charged complex compounds of iron and aluminum with fulvic or oxalic acids. It has been established that soil acidity exerts both direct and indirect acidity on the entry of radionuclides into prairie grasses (changes the cation exchange capacity). However, depending on the physicochemical properties of soils and species differences of prairie plants, the conversion rates of radionuclides into grasses can vary widely (from 0,03 to 79,91 times). Interspecies differences in ^{90}Sr accumulation depending on these properties can reach 30 or more times [30-36].

Thus, the magnitudes of translocation of radionuclides from contaminated soils into plants depend on: 1) the physicochemical properties of soils, 2) the forms of radionuclides in the soil, 3) the basic agrochemical characteristics of soils: a) mineralogical and granulometric composition, b) the content of organic matter and humus, c) soil acidity, d) indicators of the cationic composition of soil solution and soil-absorbing complex (absorption capacity of the degree of saturation of the bases).

In order environmental health of radionuclides' contaminated soil (mainly by ^{137}Cs and ^{90}Sr), it is important to use the following technologies: 1) localization, 2) deconcentration and 3) inactivation (Fig. 2). At the same time, the techniques of inactivation of these radionuclides should be recognized as a priority technology. For this, information on the behavior and distribution of radionuclides in the soil is very relevant

4 Conclusions

In general, modern environmental technologies of healthy soils contaminated by heavy metals and radionuclides are characterized by a considerable variety of action strategies (*in-situ*, *ex-situ*) and practical techniques / methods / ways. In extreme cases (very high and extremely dangerous concentrations of these pollutants in soils) it is advisable to use *ex-situ* technologies for healthy soils. In most cases, *in-situ* technology should be used for healthy soils. Among these technologies, from an environmental point of view, priorities are localization, deconcentration and inactivation. From an ecological point of view, priorities are extraction of pollutants from the soil. The effectiveness of healthy soils contaminated by heavy metals and radionuclides is conditioned by the skillful application of several technologies.

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Gallium and indium nanomaterials for environmental protection

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Abstract. Recent advances in preparation and use of gallium and indium nanoparticles and nanocomposites are briefly presented. The following applications of the obtained materials are outlined: (i) Preparation of sensors for measuring in air of gaseous pollutants (carbon monoxide, nitrogen dioxide, hydrogen sulfide, ammonia, ozone, hydrogen), vapours of volatile organic compounds (methanol, ethanol, butanol, acetone, liquefied petroleum gas), and humidity, including the basics of the sensing mechanism; (ii) removal of water pollutants by photocatalysis and/or adsorption. Finally, conclusions are drawn about the potential of gallium and indium nanoparticles and nanocomposites and the further studies needed to achieve the implementation of these materials in the real life.

1 Introduction

Gallium (Ga) and indium (In) are minor metals applied in advanced technologies needed for the society sustainable development and for our everyday comfortable life. Gallium arsenide is mainly used to manufacture integrated circuits (ICs) and optoelectronic devices. Gallium nitride (GaN) is used to produce optoelectronic devices. For example, Ga consumption in ICs was 68% of the total Ga used in 2018 in the USA, optoelectronic devices accounted for 30%, the left to 100 % was used in research and development, medicine, etc. [1]. In Europe the electric and electronic equipment (EEE) sector is the main user of Ga - 95 % of the element usage [2].

Indium is used mainly as indium tin oxide (ITO). ITO thin-film coatings are employed mainly for electrical conductive purposes in different flat-panel displays. Other In uses are alloys and solders, compounds, semiconductors and electrical components, and research [3]. In the European Union the EEE sector is the major user of In (81 %) [2]. Application of In and Ga in the advanced renewable energy technologies (solar cells, electrodes for hydrogen (H_2) production via water splitting, etc.) and the environment protection activities (pollutants sensing, monitoring and removal) is gaining increased interest recently.

Expected problems with Ga and In supply led to these metals classification in 2017 as critical for Europe materials [4] and as critical for the USA - in 2018 [5]. Materials with high supply risk and above the average economic importance compared to the other raw materials are classified as critical. Increasing the comprehensive use of those metals can be pointed out as one of the measures aimed at mitigation of their expected shortage. Application of nanosized particles (NPs) and nanomaterials, with significant surface area at low mass, may be a step in this direction. In addition, nanomaterials' characteristics are size-dependant and their properties can be tuned by changing the particles size and morphology. The exceptional properties of NPs and nanomaterials attracted the attention of scientists and a tremendous amount of work has been carried out in the area of synthesis, characterization and use of those materials in industry, medicine and the environment protection.

Work on the synthesis and use of Ga and In based nanomaterials has been increasing in the recent years. Present paper is devoted to the latest studies in this area. Applications (still niche) of Ga and In NPs and nanomaterials for green energy production and the environment protection are reviewed. An attempt is made to present examples covering the diversity of these applications.

2 Sensors for air pollution

Carbon monoxide (CO) results in elevated concentrations in the environment mainly from anthropogenic activity (industry, transport). Inhaling CO can cause headache, dizziness, fatigue, to affect hearth and damage the nervous system. Higher exposure to CO can cause sleepiness, hallucinations, convulsions, loss of consignees while extremely high exposure leads to coma and death. The Occupational Safety and Health Administration Agency (OSHA) of the USA limits the long-term workplace exposure levels, i.e. the permissible exposure limit (PEL) for human, to 50 ppm. The USA National Institute for Occupational Safety and Health (NIOSH) places airborne exposure limit (REL) at 35 ppm which should not be exceeded at any time and 200 ppm not to be exceeded during any 15-minute period [6].

Nitrogen dioxide (NO_2) is produced by automotive vehicles and industry. It is one of the main factors of the

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formation of acid rain and the hole in the ozone layer. NO_2 possesses hazardous effects on human health. OSHA places the PEL at 5 ppm averaged over an 8-hour work shift, while the NIOSH's REL is 1 ppm averaged over 10 hour shift [6]. The World Health Organization reports that short-term exposure at concentrations exceeding 200 $\mu g/m^3$ (106 ppb) NO_2 leads to significant negative health effects to humans [7]. That is why advance is needed in portable gas sensors which could detect NO_2 at ppb level.

Hydrogen sulfide (H_2S) causes nausea, dizziness and high exposure may cause a pulmonary edema. OSHA places the PEL at 20 ppm, while the NIOSH's REL is 10 ppm, which should not to be exceeded during any 10-minute period [6].

Ozone (O_3) can affect humans and animals even when it is in very low concentrations, causing irritation of respiratory system, headache and burning eyes. Continuing exposure to O_3 increases the risk of respiratory diseases, and at high concentrations O_3 has lethal effects. OSHA places the PEL at 0.1 ppm, and the NIOSH's REL is 0.1 ppm [6].

Ammonia (NH_3) is an irritant gas and its influence increases with its concentration. Higher exposures to NH_3 may cause pulmonary edema, while repeated exposure – asthma-like allergy and lung damage. Its increased concentrations in the atmosphere are due to anthropogenic sources, mainly use of NH_3 and its derivatives as agricultural fertilizers, but also - industry. OSHA places the PEL at 50 ppm, while the NIOSH's REL is 25 ppm, and 35 ppm have not to be exceeded during any 15-minute period [6].

Hydrogen (H_2) is flammable and explosive at the volume concentration higher than 4% in air [8]. It is expected to be extensively used in production of green and renewable energy in the future, so it is of high importance to develop a low-cost and effective H_2 sensor for practical use at working areas to provide early leakage and explosion warning.

Gas sensors have become a very important part of air quality monitoring, safe industry, etc. Development of commercial gas sensors based on semiconductor metal oxides (SMOs) has acquired a lot of attention, due to their low cost, and the simpe use. Due to their ability to change the conductivity when they are contacting with the gas molecules, SMOs, among them indium oxide (In_2O_3) and gallium oxide (Ga_2O_3), are widely used in the electrical detection of polluting gases. The gas measurements are based on the change in the conductivity of the sensor due to the surface chemical reaction between the sensor's surface and the reducing or oxidizing measured gases. It is commonly acknowledged that the sensing of the n-type semiconductors is controlled by the resistance changing that is brought about by the adsorption and desorption of gas molecules on the surface of the sensor [9-14] as described below. When the sensor is exposed in air, the O_2 molecules from the air capture electrons from the semiconductor's conduction band (CB). Chemisorbed oxygen species (O_2^- O^-, and O^{2-} – depending on the temperature) are generated on the surface of sensing material – equations (1-4). Electron-depleted near-surface region in the semiconductor is formed with the resulting electrical resistance of the sensor, denoted as R_a. When oxidative gas, like NO_2, is introduced into the air, it captures electrons from the CB of the semiconductor, and it also combines with the adsorbed oxygen species, equations (5-6). This results in a decrease in electron concentration in the near-surface region, thereby the depletion layer and the sensing material resistance (denoted as R_g) increase. The ratio R_g/R_a is defined as the sensor's response. The sensors are recovered by placing in air, where species, like NO_2^-, adsorbed on the sensor surface are desorbed - equation (7).

$$O_{2(gas)} \rightarrow O_{2(ads)} \quad (1)$$

$$O_{2(ads)} + e^- \rightarrow O_{2(ads)}^- \quad (< 150\ ^oC) \quad (2)$$

$$O_{2(ads)}^- + e^- \rightarrow 2O_{(ads)}^- \quad (150 - 400\ ^oC) \quad (3)$$

$$O_{(ads)}^- + e^- \rightarrow O_{(ads)}^{2-} \quad (> 400\ ^oC) \quad (4)$$

$$NO_{2(gas)} + e^- \rightarrow NO_{2(ads)}^- \quad (5)$$

$$NO_{2(gas)} + O_{2(ads)}^- + 2e^- \rightarrow NO_{2(ads)}^- + 2O_{(ads)}^- \quad (6)$$

$$NO_{2(ads)}^- + O_{(ads)}^- + e^- \rightarrow NO_{(gas)} + O_{2(ads)}^- \quad (7)$$

When the sensor is exposed to reducing gas (for example, CO, methanol or ethanol vapour, etc.) a redox reaction occurs between the adsorbed oxygen species and the molecules of the measured gas-equations (8-10).

$$2CO + O_{(ads)}^- \rightarrow CO_2 + e^- \quad (8)$$

$$CH_3OH + 3O_{(ads)}^- \rightarrow CO_2 + 2H_2O_{(g)} + 3e^- \quad (9)$$

$$C_2H_5OH + 6O_{(ads)}^- \rightarrow 2CO_2 + 3H_2O_{(g)} + 6e^- \quad (10)$$

Electrons are released and returned to the semiconductor's CB. This leads to the decrease of sensor's resistance. In this case the sensor's response is defined as the ratio R_a/R_g.

Two main directions are used to influence the interaction between the SMOs surface and target gas and thus to improve the gas sensing properties: (i) Application of nanomaterials, including decoration with metal NPs, since the performance of SMOs based sensors strongly depends on grain size, specific surface area and morphology of the sensing material. These properties can be tuned by carefully choosing the synthesis and processing conditions; (i) Doping – that improves the gas sensors characteristics by changing the energy-band structure and morphology, increasing the surface to volume ratio and as a result – creating more centers for gas interaction on the SMOs' surface. In addition, the dopant can act as catalyst that promotes the adsorption and surface reactions and hence improves the sensor performance by increasing the sensor response, reducing response and recovery time, reducing the operating temperature, and increasing selectivity.

2.1 Gallium NPs based sensors

Zinc oxide (ZnO) is one of the earliest and most often used gas-sensing materials. The similarities between ZnO and GaN gave raise to the interest in studying the gas sensing properties of GaN nanostructures. A hybrid structure,

based on GaN, namely Au@rGO/GaN nanorods (NRs), has been developed [15]. The Au@rGO/GaN NRs showed good response to 20 ppm CO that was attributed to interband transition in UV light and the localized surface plasmonic resonance in visible region. According to the authors [15], the Schottky junction (a specific property of reduced graphene oxide - rGO) contributed to the separation and transport of the photogenerated carriers. The Au NPs introduced electronic and chemical changes in the hybrid structure for improving photodetector's response towards CO.

Gallium doped ZnO (GZO) nanocrystalline films have been synthesized by radio frequency magnetron sputtering and their gas sensing properties with respect to H_2S were investigated [16]. Doping lead to enhanced sensing characteristics of the fabricated gas sensors and increased stability with respect to oxidation. Studies confirmed that among the doped films, GZO containing 3 wt. % Ga exhibited the highest sensitivity for H_2S at an operating temperature of 300 °C. The enhanced sensitivity of GZO for H_2S is attributed to the combined effect of excess oxygen vacancies due to Ga^{3+} substitution and the large adsorption energy of Ga that favours chemisorption.

Sensors based on core-shell Pt@ZnO NPs doped with 1 and 2 mol % Ga have been prepared and utilized in acetone[a] and NO_2 sensing [17]. It is found that detection limit to acetone and NO_2 of the 1 mol % Ga doped Pt@ZnO based sensor was 10 ppb and 20 ppb correspondingly.

Composite material Ga_2O_3/Al_2O_3 has been synthesized by a two-step method including hydrothermal and calcining processes [18]. It is shown that Ga_2O_3 nanorods were dispersed on the surface of mesoporous 2D Al_2O_3 nanosheets. The Ga_2O_3/Al_2O_3 composite showed relatively good NO_x (i.e. NO_2 + NO) gas sensing performance. Its response to 100 ppm NO_x at room temperature was 58.2%, being 6.5 times higher than that of pure Ga_2O_3 and remained unchanged for 30 days. The composite material showed ~6 times higher sensitivity to NO_x (100 ppm) compared to HN_3 (100 ppm), ~16 times higher sensitivity compared to CO (1000 ppm), and ~16 times higher sensitivity compared to ethanol (1000 ppm) at room temperature.

2.2 Indium NPs based sensors

Sensors based on In_2O_3 or applying In_2O_3 as doping or decorating materials in other SMOs have been extensively developed and studied recently – for both inorganic and organic gases. Below are presented some examples.

Detection of low CO concentrations at room temperature still poses some challenges. Use of nanomaterials and nanocomposites are among the often considered possible solutions to the problem. Sensing of CO (1–5 ppm) at room temperature by using Zn doped In_2O_3 nanowire (NW) transistors was shown [19]. The doped In_2O_3 NW sensor exhibited enhanced response compared to pure In_2O_3 NW. Relatively good selectivity to CO gas was achieved at comparison with NO and NO_2 (6 and 2 times higher sensor's response correspondingly). The improved response of the prepared sensor at room temperature is assigned to the created defects and to the change in conductivity of the nanowire as a result of Zn-doping.

Two materials ($In_4Sn_3O_{12}$ NPs and $In_4Sn_3O_{12}$–TeO_2 composite NPs) have been synthesized by hydrothermal route and their gas-sensing properties toward CO were examined at different concentrations (5–100 ppm) of CO in the temperature range of 100–300 °C [9]. The $In_4Sn_3O_{12}$–TeO_2 composite NPs sensor showed better sensing performance with response of 10.21, the response and recovery time of 19.73 s and of 217.5 s correspondingly for 100 ppm CO at 200 °C. The improved properties of the sensor are attributed mainly to the enhanced modulation of the potential barrier formed at the $In_4Sn_3O_{12}$–TeO_2 interface, the stronger O_2 adsorption on the TeO_2 (a p-type semiconductor), and the creation of favoured adsorption sites. The $In_4Sn_3O_{12}$–TeO_2 based NPs sensor showed selectivity (2-3 times higher response) to CO (100 ppm) over NH_3 (100 ppm), HCHO (100 ppm) and H_2 (1000 ppm).

A gas sensor based on cobalt (Co)-doped In_2O_3 NPs / molybdenum disulfide (MoS_2) nanoflowers nanocomposite has been prepared and tested with respect to CO (1, 5, 10, 50, 100, 500, 1000, 1500, and 2000 ppm) at room temperature [20]. The Co-In_2O_3/MoS_2 sensor achieved high sensitivity, fast response/recovery speed (response/recovery times = 39 s / 81 s), excellent repeatability and longterm stability (over one month). The high-performance CO sensing was attributed to the Co^{2+} ion doping and heterojunctions created at interface between Co-In_2O_3 and MoS_2.

Zinc oxide is widely used as a basis for preparing gas sensors. However, for the majority of ZnO based gas sensors, the lowest detectable concentration of CO is usually several hundreds of ppm. These values are higher compared to OSHA PEL. In order to improve the sensitivity of ZnO gas sensors for CO monitoring, In-doped ZnO semiconductor NPs (IZO NPs) materials were prepared by a sol-gel technique [21]. The materials were used to fabricate sensors that showed enhanced sensitivity to CO (50 ppm at 300 °C), compared to sensor based on pure ZnO, especially the sensors containing 1 at. % and 2 at. % In.

SMOs are promising choices for hydrogen sensors. Flame spray pyrolysis was used to synthesize palladium oxide (PdO_x)-doped In_2O_3 NPs (5 - 20 nm) [22]. From thus obtained NPs sensing films were prepared by spin coating and tested for their ability to measure H_2 at temperatures ranging from 150 to 350 °C in dry air. The studies revealed that the H_2-sensing characteristics of In_2O_3 NPs were considerably improved by PdO_x doping, especially at the optimal Pd content of 0.50 wt. %. The sensing film showed a response of 3526 towards 10000 ppm H_2 at 250 °C (the optimal working temperature), at response time of 2 s and recovery time of 180 s. Moreover, PdO_x doped In_2O_3 sensing films possessed good stability

[a] Here and further in the text where a comparison is made with volatile organic compounds their vapors are meant.

and high H_2 selectivity against different gases, such as H_2S, NO_2, C_2H_4O, C_2H_4, C_2H_5OH and C_2H_2. The sensing mechanism is described by interaction of H_2 molecules with the preadsorbed oxygen species – reactions (11 – 13):

$$H_{2(g)} \rightarrow 2H_{(ads)} \quad (11)$$

$$2H_{(ads)} + O_{(ads)}^{-} \rightarrow H_2O_{(g)} + e^{-} \quad (12)$$

$$2H_{(ads)} + O_{(ads)}^{2-} \rightarrow H_2O_{(g)} + 2e^{-} \quad (13)$$

The processes produce H_2O and release the trapped electrons back to In_2O_3 CB, thus decreasing the sensor's resistance. The improved gas-sensing behavior is assigned to the effect of the formed p-n heterojunction of PdO_x-In_2O_3 and the presence of PdO_x crystallites which catalyze the dissociation of the H_2 molecules adsorbed on the material's surface.

The number of studies on NO_2 sensor development is expanding recently. Sensors based on In_2O_3 NPs are promising in the NO_2 determination.

Packed In_2O_3 nanospheres have been synthesized via one-step solvothermal method followed by annealing [23]. The NO_2 gas sensing properties of thus prepared nanospheres were studied. The sensor showed response of 217.5 to 500 ppb NO_2, good stability and repeatability at the optimum operating temperature of 120 °C, with a detection limit lower than 10 ppb.

Doping and decoration of In_2O_3 nanomaterials with different metals is considered as a useful route for decreasing the sensors' operational temperature and the measured concentration ranges.

NO_2 sensors able to be used in ppb range of the pollutant concentrations were fabricated on the basis of Ag NPs decorated on hierarchical In_2O_3 nanospheres (Ag / In_2O) [10]. Fast response and recovery times of 30 s and 27 s correspondingly and detection limit of 0.5 ppb of NO_2 were found by using the synthesized Ag / In_2O sensor. Maximum sensitivity of 58 and 25.5 were achieved for 10 ppb of NO_2 at 120 °C for Ag / In_2O_3 sensor and primary In_2O_3 sensor correspondingly. Approximately 2.4-fold increase of NO_2 responses of the Ag / In_2O_3 sensor is observed compared to the response of primary In_2O_3 nanospheres to the concentrations ranging from 1 to 50 ppb of NO_2. Very good selectivity towards NO_2 was found – responses to 50 ppb of NO_2 were 110.2 and 265.6, respectively for primary In_2O_3 sensor and Ag / In_2O_3 sensor, compared to responses in the range of 1.3 - 2.8 and 1.6 - 4.8, respectively to 50 ppm of each of C_2H_5OH, CH_3OH, C_6H_6, $C_6H_5CH_3$, HCHO and CH_3COCH_3. The great performance of the Ag / In_2O_3 sensor is assigned to the hierarchical architecture of In_2O_3 nanospheres, the spill-over effect of metal Ag and the catalytic activity of Ag.

Ordered zirconium (Zr)-doped In_2O_3 (having Zr content of 0.5 wt%) with the pore sizes around 3 nm and undoped In_2O_3 nanostructures were synthesized via nanocasting and tested for their NO_2 gas sensing properties in the concentration range of 20-1000 ppm and the temperature range of 50-140 °C [24]. The Zr-doped In_2O_3 based sensor showed response of 169 toward 1 ppm NO_2 at the operating temperature of 75 °C, 3 times higher than that based on undoped In_2O_3. A detection limit of 20 ppb was achieved by the Zr-doped In_2O_3. At 75 °C the Zr-doped In_2O_3 sensor exhibited much higher response towards 500 ppb NO_2 against other gases (10 ppm H_2S, 10 ppm NH_3, 100 ppm ethanol, 100 ppm acetone, 1 ppm SO_2, 1 ppm Cl_2, 500 ppb O_3). The enhanced properties of the Zr-doped In_2O_3 based sensor are ascribed to the ability of Zr-doping to increase the amount of chemically adsorbed oxygen and limit crystallites' size. In addition, the increased electrons' concentration of Zr-doped In_2O_3 makes its resistance very low thus facilitating its employment in portable devices.

Li and co-authors [11] proposed NO_2 sensors based on highly ordered In_2O_3, prepared by nanocasting method using mesoporous silica as template and decorated with Au NPs. The optimal sensor, based on 0.5 wt. % Au-loaded In_2O_3, possessed a response of 472 (7.1 times higher than the response of pure In_2O_3 based sensor) and a detection limit of 10 ppb at operating temperature of 65 °C. The selectivity of the sensor towards various gases, such as NH_3 – 100 ppm, Cl_2 – 10 ppm, CH_4 – 10 ppm, H_2S – 1 ppm, CO – 10 ppm, SO_2 – 10 ppm, and O_3 – 500 ppb, was studied. The response to NO_2 was ~ 100 fold higher compared to the selectivity to other gases, except of O_3, where it was ~ 10 fold higher. The excellent sensing properties of the Au NPs decorated In_2O_3 based sensor were mainly attributed to the ordered mesoporous structure and the catalytic activity of Au.

Ag-doped hollow urchin-like In_2O_3 hierarchical nanostructures were developed by solvothermal route followed by thermal treatment. They have been tested for NO_2 detection in the concentration range of 0.05 – 1.5 ppm NO_2 and the operation temperature range of 50 – 150 °C [25]. Best results were obtained for the sensor with 1.0 mol % Ag - with response of 190 to the target gas (1 ppm NO_2) at operating temperature of 62 °C. The sensor response increased almost linearly with increasing the concentration of NO_2 from 50 to 1000 ppb. The sensors based on Ag-doped In_2O_3 hierarchical nanostructures showed relatively fast response time (~5 min) and recovery time (~8 min). The sensor based on 1.0 mol % Ag doped In_2O_3 showed higher response to 1 ppm NO_2 (over 200 fold) in the presence of various gases (SO_2, Cl_2, CH_4, CO, C_2H_4, each one – 10 ppm and C_2H_5OH - 100 ppm) at 62 °C. The enhanced NO_2 sensing performance of Ag-doped In_2O_3 is attributed to its hierarchical structure and the catalytic activity of Ag NPs.

A metal-organic frameworks-derived In_2O_3 hollow microtubes / molybdenum disulfide NPs (In_2O_3/MoS_2) nanocomposite film sensor has been prepared using a layer-by-layer self-assembly method and its sensitivity towards 0.1–100 ppm NO_2 was studied at temperature of 25 °C [26]. It is found that the In_2O_3/MoS_2 composite sensor exhibited a response value of 371.9 toward 100 ppm NO_2, which is higher than the response of individual In_2O_3 sensor (of ~ 110). The sensor possesses a good linearity in the range 0.1 – 100 ppm NO_2 and reversibility. The response value of the In_2O_3/MoS_2 film sensor to 10 ppm NO_2 is much higher than towards the same concentrations of CH_2O, NH_3, C_2H_5OH, $(CH_3)_2CO$, C_6H_6, and H_2S, indicating high selectivity towards NO_2. The In_2O_3/MoS_2 nanocomposite-based sensor showed good

repeatability and stability upon exposure to 5, 10 and 100 ppm NO_2. The enhanced NO_2-sensing properties were assigned to the synergistic effects of In_2O_3 hollow microtubes and MoS_2 NPs.

Recently, improving the sensors characteristics by irradiation with UV light has been proposed. Walnut-like In_2O_3 nanostructures have been directly grown on the interdigited electrode substrate by using a hydrothermal approach, followed by a thermal treatment [13]. The synthesized walnut-like In_2O_3 nanostructures have been used to fabricate a photoelectric gas sensor that was studied in the range of 0.1–50 ppm NO_2. A linear dependence of sensitivity on the NO_2 concentration was observed and the sensor showed sensitivity of 219 towards 50 ppm NO_2 when subjected to irradiation (1.2 mW/cm^2) of UV light (λ=365 nm). The sensor possessed response of ~ 32 to 5 ppm NO_2 in the presence of other gases (50 ppm SO_2, 100 ppm CH_4, and 100 ppm CO) at room temperature. The sensitivity to the other gases was < 5 showing selectivity toward NO_2. The high performance of the walnut-like In_2O_3 was assigned to its high specific surface area, the enhanced interface force between the gas sensor substrate and the active material and effective participation of the photo-generated electrons.

Ozone has to be monitored in industrial applications (requiring high O_3 concentrations) and for the human and the environment protection, where low concentrations have to be measured. However, the majority of the commercial sensors are properly working only in one of the concentration ranges – low (ppb) or high (ppm). Indium oxide NPs can be used to solve the problem. A cheap portable photostimulated ozone sensor, based on In_2O_3 NPs, has been developed that was able to measure O_3 in the concentration range over four orders of magnitude at room temperature by changing the diameter of the In_2O_3 NPs [27]. It is based on the findings that the 7-nm In_2O_3 NPs can detect O_3 concentration between 10 ppb and 10 ppm, while the 12-nm NPs are suitable for O_3 detection between 10 and 200 ppm. By combining the two types of NPs, O_3 in the concentration range of 10 ppb – 200 ppm can be measured. The sensors' response to 12 ppb O_3 remained stable even in the presence of 1200 ppb CO, 100 ppm CO_2, or 100 ppb NO_2. However, increasing the NO_2 concentration up to 200 ppb lead to slightly higher response than that to pure 12 ppb O_3, while the response to 40 ppb O_3 was unchanged. The sensing signal was reproducible and hysteresis was not observed in measurements conducted for 35 hours. A small influence of the low humidity on the sensor response was observed. Sensor signals were found to be reproducible in a high-humidity gas environment and thus they can be accounted for. By sealing the sensor chamber with a porous hydrophobic membrane, which prevented the passage of liquid water, submerged measurements were carried out [28].

An organized monitoring of NH_3 concentrations is essential for decreasing the hazard for human health and plants. Regardless of this, the measurement of atmospheric NH_3 in urban areas has been usually unconsidered, since its average concentrations are generally low (in the 20–30 ppb range). A low-cost sensor based on a mixture of single-walled carbon nanotubes (SWCNT) bundle layers with indium-tin oxide (ITO) NPs was prepared on plastic substrate [29]. The sensor exhibited high sensitivity to NH_3 (detection limit of 13 ppb) when used at room temperature. It displayed short recovery time and high selectivity in the presence of acetone and ethanol. The functionalized SWCNT exhibit a resistivity decrease when are exposed to water concentrations representative for ambient air (in the ppm range), revealing the possibility to differentiate the impact of interfering water vapour signal in the NH_3 measurement.

Methanol (CH_3OH) vapour causes headache, irritation of the eyes and mucous membranes. The repeated exposure to CH_3OH vapour may lead to metabolic acidosis, serious visual impairment, difficult to breathe. The OSHA PEL is 200 ppm, while the NIOSH REL is 200 ppm, and 250 ppm have not to be exceeded during any 15-minute period [6].

Pure ethanol (C_2H_5OH) irritates the skin and eyes. OSHA placed the PEL at 1000 ppm and the NIOSH's REL is also 1000 ppm [6]. Recently some studies have paid attention to the health risks related to inhalation of C_2H_5OH vapour [30].

Acetone ($(CH_3)_2CO$) vapour is irritating; exposure to its high concentrations affects eyes, nose and throat. The acetone PEL is 1000 ppm, the REL is 250 ppm [6].

The liquefied petroleum gas (LPG) vapour, when present in high concentrations in the air, can cause suffocation with symptoms of headache, dizziness, weakness, nausea, vomiting. The LPG PEL is 1000 ppm averaged over an 8-hour work shift, while the REL is 1000 ppm averaged over 10 hour shift [6].

Exposure to n-butanol vapours can cause headache, dizziness, nausea, vomiting. OSHA's PEL is 100 ppm averaged over an 8-hour work shift, while the REL placed by NIOSH is 50 ppm which should not be exceeded at any time [6].

In order to protect humans and the environment, sensors are needed that are able to detect the above-mentioned vapours.

Anand and co-authors synthesized pure and Ag-doped (1, 3 and 5 % Ag) In_2O_3 NPs by the co-precipitation method and studied their sensing properties towards CH_3OH, C_2H_5OH, $(CH_3)_2CO$ and LPG at different operating temperatures [31]. Best results were obtained with 3% Ag-doped NPs whose maximum response (R_a/R_g) was ~30 towards C_2H_5OH at the operating temperature of 300 °C, ~15.5 towards $(CH_3)_2CO$ at 350 °C, ~17 towards LPG at 400 °C and ~12 – towards CH_3OH at 300 °C – at the concentration of 50 ppm of each tested gas. The response time for In_2O_3 – 3% Ag sensor was between 6 and 32 s while for undoped In_2O_3 sensor – between 10 and 40 s, depending on the measured concentration. The improved sensing performance of 3% Ag-doped NPs based sensor is assigned to (i) the large number of oxygen vacancies leading to increased amount of O_2 adsorbed on the sensor surface as compared to pure In_2O_3 sensor, and (ii) the catalytic effect of Ag – Ag improves the sensor response by the formation of activated species of the chemisorbed analyte, which are

then spilled onto the surface of In_2O_3. That results in fast reaction between the analyte molecule and oxygen.

Liu and co-authors further decreased the optimum measuring temperature and the concentration range (from 1 ppm to 50 ppm) by demonstrating C_2H_5OH gas sensor based on indium oxide / molybdenum disulfide (In_2O_3/MoS_2) nanocomposite prepared via hydrothermal route [12]. The reported sensor response at 260 ºC for In_2O_3/ MoS_2 composite was ~36, while for pristine In_2O_3 it was ~ 14 at 280 ºC. The responses of the two sensors show almost constant value to 50 ppm of C_2H_5OH at 260 ºC over 50 days, demonstrating the high stability of these sensors. The In_2O_3/MoS_2 sensor showed selectivity to C_2H_5OH (150 ppm) in presence of C_6H_6 (250 ppm), $(CH_3)_2CO$ (350 ppm), NH_3 (450 ppm), and H_2O (5500 ppm). The improved characteristics of In_2O_3/ MoS_2 nanocomposite sensor, compared to pristine In_2O_3 sensor are assigned to the large specific surface and good electrical properties of MoS_2, as well as to the synergistic effect between In_2O_3 and MoS_2. It is suggested that the MoS_2 nanosheets provide a platform for attaching In_2O_3 NPs, hampering their interparticle aggregation and providing more active sites for the adsorption of C_2H_5OH molecules. It is concluded that the fabricated nanostructure favors molecular adsorption, gas diffusion and mass transport, thus improving the gas sensing performance.

Shruthi and co-authors prepared sensor based on Y_2O_3-In_2O_3 nanocomposites [14] and conducted gas sensing studies under room temperature. The Y_2O_3-In_2O_3 sensor responses of ~923 and 3.722 were found towards 200 ppm and 1 ppm CH_3OH correspondingly. The response and recovery times of Y_2O_3-In_2O_3 were 13 and 18 s respectively and the sensor showed stability over 30 days. The response and Y_2O_3-In_2O_3 gas sensor towards 200 ppm CH_3OH in presence of other gases (ethanol, n-butanol, acetyl acetone, ammonia, isopropanol, xylene, toluene, 2-methoxyethanol, acetone, and cyclohexane – each one 200 ppm) at room temperature was between 4.5 and 20 times higher compared to the response to the other gases thus proving the sensor's high selectivity. The enhanced properties of Y_2O_3-In_2O_3 sensor were explained by the formation of a n-n hetero junction between Y_2O_3 and In_2O_3 and the appearance of built-in potential.

Porous In_2O_3 NPs (20 - 50 nm) were prepared using a solvothermal method and studied as gas-sensing material for n-butanol – 50 ppm [32]. At 140 °C the sensor showed responses of 5.5, 10.3, 20.5, 32.4, 54.7, 97.3, and 241 for n-butanol concentrations of 5, 10, 15, 20, 30, 50, and 100 ppm, correspondingly. The sensor exposed to 50 ppm of other gases (ethanol, acetone, formaldehyde, benzene, xylene, methanol, ammonia, and n-butanol) exhibited good selectivity to n-butanol vapor. The good response of In_2O_3 NPs was assigned to their large specific surface area and porous structure that can provide more reactive sites and allow successful transfer of gases.

In some cases In_2O_3 is used as one of the components of nanocomposite applied as a sensing material. Humidity detection and measurement is one of the important parameters in the environment monitoring. Graphene oxide/Nafion/indium oxide (GO/Nafion/In_2O_3) nanocomposite - based humidity sensor has been made-up and tested under a wide relative humidity range (RH = 11–97 %) at 25 °C [33]. The GO/Nafion/In_2O_3 film humidity sensor exhibited high sensitivity (especially at RH > 80%), low hysteresis, good stability and repeatability. The sensor work is based on the increase in the capacitance with the increase in the RH, since the amount of water molecules physisorbed on the sensor surface increases as RH increases. The water molecules, possessing a dipole moment, can increase the capacitance of the nanocomposite.

Doping of other materials used for sensors with In compounds improves the performance of these materials. Crystalline ZnO nanorods were modified by In_2O_3 NPs using PVP as a morphology control agent via sol-gel and the hydrolysis method and the obtained material was used to prepare sensor for n-butanol vapor [34]. Tests showed that the In_2O_3/ZnO sensor response was 104.3 towards the n-butanol concentration of 100 ppm at 370 °C. This was 3.5 and 5.3 times higher than the response of the pure ZnO and In_2O_3 sensor, correspondingly. The response and recovery times of the In_2O_3/ZnO sensor were 6 s and 9 s at the gas concentration of 4 ppm. The response of the In_2O_3/ZnO sensor containing 3.3 mol % of In was 6.1 at n-butanol concentration of 1 ppm, showing good detection. The In_2O_3/ZnO sensor exhibited high selectivity to n-butanol (100 ppm) in the presence of ethanol, methanol, acetone, and ethyl acetate (each one 100 ppm). The enhanced sensing performance was ascribed to the 1D single crystalline nature of ZnO nanorods and the heterostructure established between In_2O_3 and ZnO nanorods.

3 Water pollutants removal

The scientific work has shown that the photocatalytic degradation of toxic organic pollutants is one of the most efficient methods for surface water purification. Ga and In NPs and nanocomposites are gaining their place in this area. The photochemical pollutant removal can result from direct or indirect interactions, or from the both types of reactions – Fig. 1. In the direct reaction pathway (Fig. 1a) the photogenerated holes (or electrons) directly oxidize (or reduce) pollutants that are adsorbed on the photocatalyst surface. In the indirect path (Fig. 1b) the excited electrons move to the surface of photocatalyst and react with O_2 to generate superoxide radical anions ($\bullet O_2^-$). At the same time, the corresponding holes move to the exterior of the photocatalyst and oxidize the water molecules or hydroxyl groups, present on its surface to produce hydroxyl radicals (•OH). Thus formed reactive radical species are able to decompose and mineralize pollutants into CO_2, H_2O and other inorganic species [35]. The light utilization efficiency, cost-performance ratio, and secondary toxicity are the major anxieties in the photocatalytic pollutants' removal.

3.1 Gallium NPs based materials

Titanium dioxide (TiO_2) NPs in anatase form are often used as photocatalyts. Anatase NPs doping with Ga by

applying sol-gel method is reported [36]. The NPs obtained (with size of around 15 nm) were used to study the photocatalytic degradation of organic dye solution (Rhodamine B) as a model pollutant under UV irradiation. Nearly 90% degradation efficiency was achieved within 3 hrs of UV irradiation when Ga-doped TiO_2 NPs were used, which is faster than the Rhodamine B degradation by undoped samples. The effect is ascribed to the fact that doping levels were created within the bandgap of TiO_2. These levels act as trapping centers to suppress the recombination of photogenerated electrons and holes. In this way proper utilization of charge carriers is achieved for the generation of strong oxidizing radicals able to degrade the organic dye. Consequently the derived Ga doped TiO_2 NPs can be used for light-assisted oxidation of toxic organic molecules in the surface water for the environment protection.

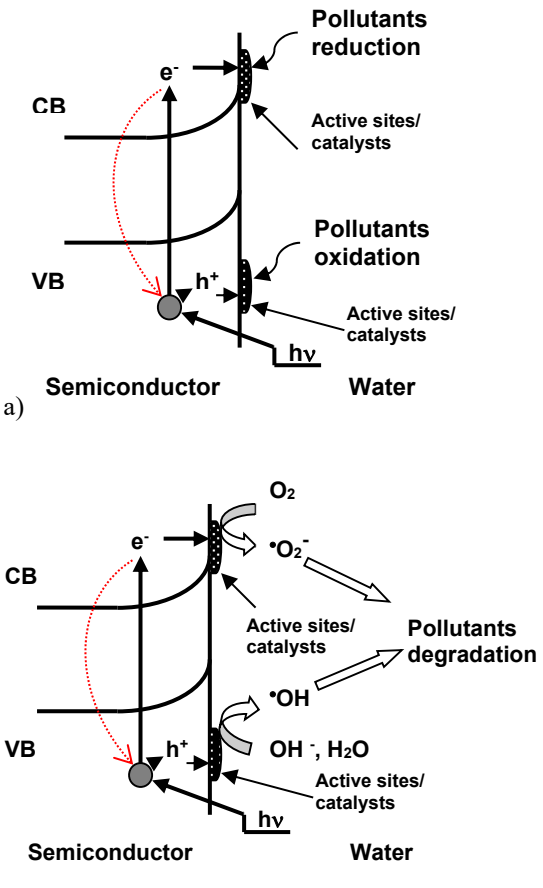

Fig. 1. Schematic representation of electron-hole pairs photo-generation and their participation in pollutants removal: a) direct pollutants oxidation and/or reduction, b) indirect pollutants decomposition. Red dashed arrow – a possibility for recombination of photogenerated electrons and holes.

Fluoride ion (F^-) is mobile under natural conditions and can appear in elevated concentrations in water due to natural leaching of rocks. However, most often its high concentrations are due to anthropogenic activities such as metals' extraction, electroplating, etc. When F^- presents in drinking water in concentrations higher than the recommended, it can cause dental and skeletal fluorosis. With the aim to reduce the F^- concentration in water, different methods have been developed, such as adsorption, ion exchange, precipitation, and membrane processes. Most of them are feasible when applied to point pollution sources. Adsorption can be applied also to polluted water discharged from diffusion pollution sources if the loaded adsorbent can be collected. Use of nanosorbents with magnetic properties is a big step in this direction. Improved selectivity and chemical reactivity are the other desired features of those adsorbents. As contribution in this area Fe_3O_4 NPs were synthesized by coprecipitation of Fe^{2+} and Fe^{3+} under alkaline conditions and their surface was then modified with 3-aminopropyltriethoxysilane (APTES) [37]. The Fe_3O_4/APTES NPs were further modified by grafting Ga tetrakis (4-carboxyphenyl) porphyrin groups at their surface. The batch experiments using thus prepared NPs showed that they can be applied to remove F^- from aqueous solution. Extraction efficiency over 96% was achieved at an initial F^- concentration of 10 mg/L, pH 5.5 and contact time of 30 min. The Fe_3O_4/APTES/Ga nanosorbent was successfully regenerated by using NaOH solution. The recovery of F^- ions from the adsorbent under optimum conditions was 98%. The fluoride removal efficiency by the Fe_3O_4/APTES/Ga nanoadsorbent in 5 adsorption / regeneration cycles was 97.2%, 96.8%, 95.5%, 94.3%, and 87.0% correspondingly, showing the adsorbent stability.

3.2 Indium NPs based materials

In this application mainly indium sulfide (In_2S_3) materials are used, based on their photocatalytic properties. Due to its stability and low-toxicity In_2S_3 (with UV-Vis-NIR – solar-spectrum) can be used as promising photocatalyst and a sensitizer for other semiconductors with photocatalytic properties. The proper separation and transport of photo-induced charge carriers is one of the promising ways for improving the efficiency of In_2S_3-based materials for pollutants' removal. Efforts have been made to decrease the recombination of photogenerated electron-hole pairs by morphology design, doping or producing heterostructured materials. The studies on nanosized In-based materials usage for water pollutants removal are devoted mainly to organic dyes, pharmaceuticals and microorganisms removal.

Gao and co-authors [38] have controlled the morphology of In_2S_3 NPs, thus adjusting the mass-transfer pathway for the photocatalytic removal of pollutants in the liquid-phase system. The tetragonal In_2S_3 NPs with size of 5–20 nm, synthesized by them, showed stable photo-catalytic removal of methyl orange (MO) over the entire solar light spectrum - under UV light (96.2% within 30 min), visible light (95.4% within 3 h) and near-infrared light (67.2% within 3 h). The broad light absorption region of the synthesized NPs is assigned to the presence of a defect band located above the VB of In_2S_3.

Wu and co-authors [39] prepared a porous 3D microsphere-like In_2S_3, stacked by 2D ultrathin nanosheets, which showed 3 times higher photo-degradation efficiency with respect to MO compared to 3D solid microsphere-like In_2S_3. The better photocatalytic

activity was attributed to the relatively higher specific surface area and the presence of more reaction sites, which accelerated the surface separation of photo-induced charges and the inter-facial charge-carrier transfer.

Li and co-authors [40] prepared In_2S_3–TiO_2 nanotube array composites by CV, potentiostatic and pulse electrodeposition. Their studies showed that the pulse prepared In_2S_3–TiO_2 yielded the highest and stable photocurrent response, consequently showing an excellent photocatalytic activity in the degradation of p-nitrophenol. It was considered that the homogeneous, ultra-fine structure of In_2S_3 NPs lead to a high charge separation efficiency resulting in improved photocatalytic activity.

Self-organized TiO_2 nanotubes (NTs) array was decorated with In_2S_3 NPs to obtain (In_2S_3/TiO_2 NTs) hybrid that exhibited strong absorption in the visible light region and enhanced photocurrent density [41]. The In_2S_3/TiO_2 NTs showed higher photocatalytic activity when compared to that of bare TiO_2 NTs in the degradation of herbicide 2,4-dichlorophenoxyacetic acid (2,4-D) under simulated solar light. Approximately 100 % removal of the 2,4-D was achieved for 160-min irradiation by using the optimum In_2S_3/TiO_2 NTs composition. The removal efficiency was 95.1 % after 10 successive cycles. The photocatalyst has shown a good stability and easy recovery that gives grounds for its potential application for the photocatalytic removal of some organic pollutants from water.

Indium sulfide / zinc germanate (In_2S_3/Zn_2GeO_4) composites, with different In_2S_3 concentrations, were prepared via a co-precipitation hydrothermal method [42] and tested for their ability to decompose acetaminophen (APAP). The composite containing 30 mass % In_2S_3 showed the best activity for APAP degradation under visible light, with better performance compared to In_2S_3, nitrogen-doped TiO_2, TiO_2 powder (Degussa P25), and Zn_2GeO_4. The studies revealed that holes and formed superoxide radicals were mainly involved in the photodegradation of APAP.

Hierarchical nanoflower superstructures consisting of In_2S_3 nanosheets grown on a Bi_2S_3 nanoflower backbone (Bi_2S_3/In_2S_3) were prepared by a solvothermal route, rest on different growth rates of the two sulphides [43]. The as-prepared Bi_2S_3/In_2S_3 material exhibited notable visible-light photocatalytic activity and stability in the degradation of 2,4-dichlorophenol. This is assigned to the presence of In_2S_3 nanosheets on the surface of the Bi_2S_3 nanoflowers which lead to increased visible-light response and enhanced photogenerated charge transport and separation steered by the heterojunction.

Hollow β-In_2S_3 NPs with high surface area have been synthesized by means of anion exchange process under a hydrothermal condition without any surfactant or sacrificial agent [44]. Adsorption capacity and photocatalytic activity of the newly prepared material were assessed, using methylene blue (MB) under dark and visible light irradiation. The big adsorption capacity (ca 158 mg/g in 60 min) for MB in the solution, realized in a fast process, was assigned to the high specific surface area (324.6 m^2/g) of the β-In_2S_3 NPs and to the electrostatic interaction between the negatively charged surface of β-In_2S_3 and the MB. After the adsorption reaction, visible light photocatalytic reaction further decreased the concentration of the still existing MB. The removal efficiency for 100 mg/L of MB solution was 73.4% under dark for 60 min (indicating that adsorption plays an essential role for removing MB), and after further visible light irradiation for 180 min increased to 92.2%.

Tetragonal prismatic γ-In_2Se_3 NPs with the (110) facets were synthesized hydrothermally in the presence of ethylenediaminetetraacetic acid (EDTA) that plays a key role in the exposed facets regulation [45]. Studies on the photocatalytic decomposition of tetracycline (TC) by the newly synthesized material showed that the γ-In_2Se_3 NPs prepared with 0.04 M EDTA had the optimal activity ensuring degradation of TC in 120 min with an efficiency of 91.5%.

Gao and co-authors [46] investigated the visible light photocatalytic disinfection of water by using a photocatalyst prepared via joining non-woven carbon nanofibers (CNF) and In_2S_3 nanoflowers to construct three-dimensional hierarchical CNF–In_2S_3 nanostructures with large specific surface area and enhanced light absorption. Approximately 80 % of *Escherichia coli* cells were killed by CNF-In_2S_3 under visible light irradiation owing to the occurrence of oxidative stress. The good activity of the CNF-In_2S_3 photocatalyst was attributed to the enhanced light absorption, large surface area, and efficient charge separation that facilitate production of oxidizing species.

4 Conclusions

In conclusion, it can be said that Ga and In NPs and nanocomposites are materials showing potential for application in environmental protection. Materials based on Ga and In NPs are proposed for sensors for determining inorganic and organic polluting gases. In this application further work is needed in direction of increasing the response and selectivity in the low ranges of the measured concentrations, and of long-time stability of the prepared sensors (since most of the studies cover only 30 days).

In the water pollutants removal application most of the studies have been conducted with organic dye solutions. Consideration of other types of pollutants seems interesting. More data on the pollutants' decomposition products and investigations on the ways for collecting and separating from the water of the already used photocatalysts are needed.

The improvements in all above-mentioned directions can not be achieved without further research on the mechanisms of the proceeding reactions and phenomena and on the impacting factors.

Ending, we can say that Ga and In NPs and nanocomposites are promising materials but still much work is required for their implementation in the real life devices.

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Utilization of mine water of Kryvbas as an imperative for sustainable development of Dnipropetrovsk region

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Abstract. Sustainable development is a wide area of scientific discourse based on the interdisciplinary approach that integrates research in the natural, technical and social sciences. It is a multidimensional concept that reveals complex interactions between society, economy and environment. This work highlights problems of sustainable development of old industrial regions with the dominance of the mining industry. The latter creates a high human burden on the environment and leads to ecological and social problems. One of the most important tasks of ensuring the long-term environmental sustainability of the Dnipropetrovsk region in Ukraine is utilization of highly mineralized mine water of Kryvbas. From the standpoint of sustainable development, mine water should be considered as a hydro-mineral resource of many valuable components including bromine. In this work we justify the creation of bromine production from mine water of Kryvbas. Potential profitability of the production is largely based on innovative technical and technological solutions. We examine the market and many aspects of the pilot project, including its technological, investment and economic specifics. We highlight the relevance of this project and suggest a possibility for its implementation within the regional strategy framework.

1 Introduction

Sustainable development is a comprehensive interdisciplinary concept that covers different levels and areas of human life. It aims to bridge the gap between natural, technical and social sciences and to focus collective efforts on difficult challenges.

It is a multidimensional concept that investigates complex interactions between society, economy and environment. That is why most studies, particularly [1-3], examine three dimensions of sustainable development:

1) social solidarity (inclusive growth with equal opportunity for all people, poverty eradication, improving the well-being, gender equality, safety, social cohesion);
2) economic efficiency (economic growth, increased trade, employment, optimal use of limited resources, technological development, innovations, increased investment and productivity);
3) environmental responsibility (safeguarding the environment, keeping the equilibrium and integrity of ecosystems, waste management, control of climate change, biodiversity conservation).

The balanced development of these components is also important. N. Derlukiewicz [1] emphasizes that according to the sustainable development concept, future needs can be met depending on how well social, economic, and environmental objectives or needs are balanced.

S. Talukdar [4] conceptualizes sustainability in terms of environmental, physical, social and economic dimensions of sustainability. He also identifies two sustainability goals: continuity and aspiration.

D. Hanss & G. Bohm [5] discuss such dimensions of sustainability as environmental, social, developmental, temporal, and economic. According to the authors, development, new technologies, research and unsolved problems belong to developmental dimension of sustainability. We agree with this classification and use its elements in our case study. We think that this developmental dimension may also be called "innovative".

E. Holden et al. [6] examines four primary dimensions: safeguarding long-term ecological sustainability, satisfying basic human needs, and promoting intragenerational and intergenerational equity. The authors also underline the distinction between narrow and broad sustainability. The narrow sustainability places great emphasis on long-term ecological sustainability. The broad sustainability also includes a wide range of political, social, economic and cultural issues.

Sustainable development is not only a scientific concept, but a political vision too. There are many regional, national, and global sustainability studies that have been successfully used in policymaking.

But eventually, we agree with I. Ilic-Krstic et al. [2] that the general concept of sustainability can have different forms depending on the framework being used. In the context of this study, the attributes of sustainable

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development are important for solving regional- and project-level problems.

The sustainable development approach is of particular significance to address the challenges in old industrial regions. Basic industries are dominant in these regions, because they were mostly formed and developed long ago.

Old industries are primarily based on extensive use of local raw materials, have outdated technologies, low productivity and accumulated environmental problems. Therefore, structural modernization is one of the key challenges in transformation of old industrial regions.

A number of researchers investigate problems of old industrial regions and a possibility of their neo-industrial modernization, see [7-11].

K. Birch et al. [7] studies diverse experiences among old European industrial regions and the role of national varieties of capitalism in shaping regional trajectories and the different mechanisms of regional adaptation. L. Coenen et al. [8] analyzes the potential, barriers and limitations for regional innovation policy to facilitate industrial renewal in old industrial regions.

The authors of [10] analyze how to ensure future sustainable development of old industrial coal-mining regions. The authors emphasize that there is no need for drastic changes, such as radical transformation in technologies, business organization patterns, or composition and quality of used resources (including labor). Instead, one may start with using technologies and business models that have a possibility to diversify the current economic activity. This possibility comes from similarity in the knowledge base and workers' qualification between different industries that are not connected both in the value chain and in the goods-dependent trade. An example of such diversification for the old coal-mining regions is a circular production that returns coal mining and enrichment waste back into production cycle by using innovative technologies.

Continuing research in this direction, we substantiate one of the possible project-level solutions as part of ensuring the long-term sustainability of the Dnipropetrovsk region in Ukraine.

2 The problem of Kryvbas mine water utilization

Dnipropetrovsk region is one of the most industrialized regions of Ukraine. According to State Statistics Service of Ukraine, it makes one fifth of Ukrainian industrial product sales.

The mining industry (27.2% of total sales in 2018) and metallurgical production (37.7% of sales) are the key industrial sectors of the region; they form basis of a powerful mining and smelting complex.

However, these industries are medium-low-tech. This leads to unsound technological structure, which is worse than the structure of other industrial regions. The structural and technological modernization of the region is blocked for institutional, political, functional and other reasons. At the same time, these sectors create a high human burden on the environment and worsen the ecological and social situation in the region.

Kryvbas (Kryvyi Rih Iron Ore Basin) is the largest ore mining region in Ukraine. Mining operations form a significant amount of mineralized water that is usually discharged into natural water sources. There are different options to drain, process and use mine and quarry waters of Kryvbas, but all of them have shown to be flawed [12].

As indicated in the current Strategy for development of the region until 2020: "Dnipropetrovsk region is one of the worst in terms of access to qualitative drinking water. Most of its cities entered a pre-crisis or crisis hydrological and ecological situation because self-recovery of the Dnieper and many rivers of the basin can no longer restore the upset ecological balance. The quality of surface water does not meet requirements of economic and household consumption. One of the main problems of the region is the pollution caused by mine water" [13].

As stated by a number of regional environmental programs (e.g. the Dnipropetrovsk regional comprehensive strategy of environmental safety and prevention of climate change for 2016-2025, and the long-term program to solve the environmental problems of Kryvbas for 2011-2022) protection and sustainable use of water resources, as well as purification and processing of highly mineralized mine water are the two priority directions for development of the region.

One of the most important aspects of mine water processing is the extraction of valuable components. According to experts [14], up to 20 million m^3 of highly mineralized mine water is pumped out in Kryvbas every year. Notably, this water contains bromine in such concentration that allows us to consider its industrial production.

In this work we justify the creation of bromine production from mine water of Kryvbas.

3 Extraction of bromine from mine water of Kryvbas

3.1 Market aspect

Until recently, the domestic needs of Ukraine for bromine and its derivatives were fully provided by the industrial production of bromine from the Lake Sivash brine in PJSC Brom, Crimea. According to Statista [15], Ukraine produced around 3500 metric tons of bromine in 2013. According to State Statistics Service of Ukraine, the annual revenues from bromine export were around $ 1 mln.

However, due to the annexation of Crimea Ukraine lost its bromine production and is forced to purchase imported bromine-containing products. The resulting changes in the supply/demand balance of bromine in the domestic market actualize the idea of extracting bromine from the mine water of Kryvbas.

According to [16], about 820 000 tons of bromine are produced globally every year. Over the past 15 years the market price of bromine has increased 7 times. The

leading countries producing bromine and its compounds are USA, Israel, Jordan, China and Japan. They account for 98% of world production, see Table 1 compiled according to the data of [15, 17].

Table 1. Major countries in worldwide bromine production.

Country	Bromine production in 2018, ths tons	Bromine concentration by source, g/l
USA	-*	Brine wells – 2-6 Dead Sea brine – 10-12
Israel	190	Dead Sea brine – 10-12
Jordan	100	Dead Sea brine – 10-12
China	60	Underground wells – 0.2-0.3 Sea water – 0.05
Japan	20	Sea water – 0.05
Ukraine (temporarily occupied territory)	4.9	Shallow sea – 0.6-1
India	1.7	Lake – 3-4

*Figures for the U.S. have withheld to avoid disclosing company proprietary data.

The demand for bromine is growing (by 1-2% per year on average) because of its widespread use. Nowadays, a lot of bromine is used in production of flame retardants, which protect organic materials from ignition. A significant amount of bromine is also consumed in production of drilling fluids that are used for drilling oil and gas wells. Another area of bromine use is production of pesticides and insecticides for agriculture. Elemental bromine and its compounds are also used in water cleaning and treatment. Bromine is sometimes used for mild disinfection of pool water instead of chlorine. Other application areas of bromine compounds are pharmaceuticals and cosmetics, photographic chemicals, desiccants for cooling systems, dyestuffs, lead scavenger in anti-knock fuels, monomers for specialty polymers, bleaching and oxidizing chemicals, precision cleaning [17-19].

3.2 Technological aspect

The choice of bromine extraction technology mostly depends on concentration of bromide-ion in water. For instance, steam desorption is used to extract bromine from the Dead Sea brine, while air-desorption is used in extraction at Lake Sivash.

The concentration of bromide-ion in the mine water of Kryvbas requires the air-desorption extraction method. In this case, the main limiting stage of production is a desorption process that occurs in a countercurrent packed apparatus (desorber). For example, a titanium desorber loaded with a plastic screw packing is nowadays used in the industrial practice [20].

The high cost of titanium significantly affects the capital costs. This actualizes the search for ways to drastically reduce the size and metal/material consumption of technological equipment and, first of all, the desorber as the largest unit.

As part of a pilot project that recycles 500 m^3 of mine water per hour in Kryvbas, we propose an innovative solution that greatly reduces the capital costs, see Table 2.

Table 2. Comparative analysis of the technical characteristics of traditional and innovative core equipment.

Indicators	Desorber	
	Traditional	Innovative
Material	Titanium	Titanium
Diameter, m	4.6	2.0
Packed bed	Screw-type	Screw-type
Height of packed layer, m	12	4
Irrigation intensity, $m^3/m^2 \cdot h$	30	150
Air velocity, m/s	1.4	5.7
Hydrodynamic regime	Film	Flooding
Extraction rate, %	88	88
Packed bed volume, m^3	199.3	12.6
Titanium consumption, tons	20.8	4.5

The project is based on the air-desorption method and using a critical hydrodynamic flooding regime. The latter provides an extremely high productivity and efficiency but is very unstable and may cause a technological disaster by flooding countercurrent packed apparatuses with gas/liquid emulsion. Therefore, this regime is generally considered a strict taboo.

Our innovative idea is to make the flooding regime work without disasters by making it stable both under constant and variable loads with the help of its hydraulic self-organization. The implementation of this idea was made possible due to the synergistically oriented architecture of the desorber, which has demonstrated promising results during pilot tests.

The scientific novelty consists in the new flow organization, which depending on the relative position of the desorber and fan looks as shown in Figure 1, where L – liquid flow (mine water), G_1 and G_2 – main and additional air flows, and quantitatively, G_2 is at least 3-5% of $G = G_1 + G_2$.

Such flow organization provides hydraulic self-organization of the flooding regime and makes it working.

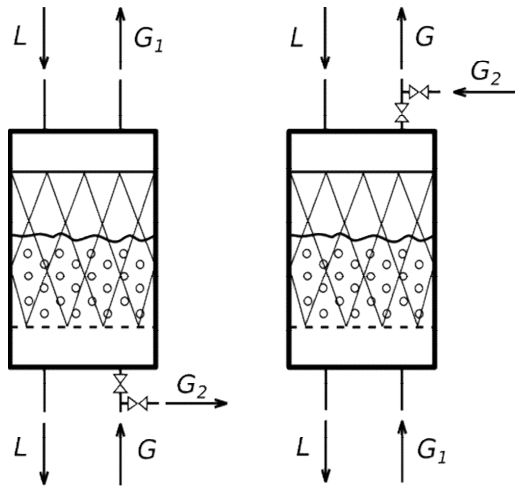

Fig. 1. The scheme of irrigated packed bed with pumping (at the left) and suction (at the right) of air.

3.3 Economic and investment aspect

We conducted a preliminary economic assessment of constructing a bromine extraction unit. For calculations we used mine water processing volume of 500 m^3/h with a mass concentration of bromide equal to 120 mg/l; the annual production capacity is 400 tons. The initial data and resulting performance of the proposed pilot project are given in Table 3.

Table 3. Pilot project performance indicators.

Indicators	Value of the indicator
Initial data	
Production capacity, tons per year	400
Annual sales, $ mln	0.98
Initial investment (excluding infrastructure costs), $ mln	0.72
Construction period, months	30
Production cost, $ ths/ton	1.08
Risk-adjusted discount rate, %	15
Investment horizon, years	5
Calculated performance indicators	
Discounted payback period, months	52
Net present value, $ mln	0.24
Internal rate of return, %	28.6
Profitability index	1.39

The implementation of this project is justified by its technical and economic indicators, the possibility of import substitution and 55 new work places that it creates. This project will diversify the country's chemical production and strengthen its economic security.

A promising option for the utilization of bromine-containing mine water of Kryvbas is production of calcium bromide, which is the main component of drilling fluids.

The traditional technology of calcium bromide production is based on reaction between liquid bromine and calcium hydroxide in the presence of a reducing agent (urea, formic acid or ammonia).

When bromine is extracted by air-desorption, the production process can be simplified and cheapened by absorbing bromine with calcium hydroxide directly from bromine-air mixture. In this case, the steps needed to obtain liquid bromine are skipped, leading to significant cost reduction of the final product [21].

In case of successful implementation of the pilot bromine extraction project, it can be scaled in order to greatly increase the production of bromine and/or its compounds. Future development of this project is associated with organization of complex processing of mine water (that contains sodium chloride, magnesium, potassium and other valuable components [14]) with a goal to obtain several target products.

The important aspects of the project are its business model and sources of financing. The lack of practical solution to the problem of mine water utilization in Kryvbas throughout years proves that it cannot be solved only with principles of market self-organization and private entrepreneurial initiative. It may be necessary to use mechanisms of public-private partnership (PPP) or even a public-private-international partnership.

A water management industry typically has a number of factors that restrain the implementation of PPP mechanisms. As indicated in [22], these factors include: (1) high cost and unprofitability of the industry from environmental and economic standpoints, (2) low quality of source water and potentially high penalties for water pollution, (3) low profitability of the water supply sector due to underestimation of water resources.

In contrast to solutions suffering from the listed restraining factors, we suggest a project that can take full advantage of the PPP mechanisms. Our project has a socio-environmental importance, commercial effectiveness and an innovative component. Mixed financing of the project can be carried out with resources of the State Regional Development Fund, environmental funds, international technical assistance, own funds of mining enterprises, and other investors. Depending on the sources of investment, various business models can be considered to implement the project. Examples of such models are given in [23].

4 Implementing the sustainability project within a regional strategy framework

The success of any project is largely determined by the institutional framework for its implementation. Currently, significant opportunities for implementing sustainability projects with innovative components are opening up within a regional development framework.

A distinctive feature of current regional development strategies is the use of smart specialization approach. In [24], we proved that the Dnipropetrovsk region has prerequisites to form smart specialization domains based on the development of chemical production.

In line with this idea, we propose a pilot project to create an innovative import-substituting production of bromine and/or its compounds from mine water of Kryvbas as a regional development project. Table 4 shows that our project proposal meets the key criteria for prioritizing regional development projects.

The project proposal meets the objectives of Strategy for Development of the Dnipropetrovsk region until 2027: A.1.1. "Development of high-tech and innovative industries"; B.2.2. "Improving the industrial waste management system" and the smart-objective "Developing potential of the chemical complex".

In the context of this study, it is important that connecting smart and sustainable growth through smart specialization approach is possible [25]. The project proposal has a positive impact on the main dimensions of sustainable development, including social, economic, environmental and innovative dimensions, see Table 5.

The regional report "Sustainable Development Goals: Dnipro-2030" [26] specifies the region's conditions and objectives within the national Sustainable Development Goals (SDGs).

According to the expert recommendations on determining priority measures to achieve the SDGs of

the Dnipropetrovsk region, the achievement of SDG-9 "Industry, innovation and infrastructure" will be facilitated by "development of enterprises based on the newest industrial waste processing technologies and obtaining cheap raw materials for the chemical and construction industries" [26, p. 150]. Our proposed project meets these recommendations and contributes to implementation of other regional goals:

Table 4. Conformity of the project proposal with key criteria for prioritizing regional development projects.

Criteria	Compliance with criteria
Significance	
Alignment with the regional Strategy	The project has an obvious contribution to more than one strategic goal (program)
Impact of the project	The project has an impact on the entire region (if scaled)
Project focus	Business project with societal and environmental components
Administrative feasibility	The project provides for a partial involvement of regional authorities
Readiness for implementation	
Project status	There are the idea and preliminary calculation of the project
Funding	Cost structure and funding source are partially substantiated
Non-financial resources	There are scientific and technological developments, hydro-mineral resources, qualified project executors

Table 5. Impact of the project proposal on the dimensions of sustainable development.

Dimensions	Impact
Social	Creation of new jobs. Formation of new social needs and new market segments in the future
Economic	Increase in gross regional product. Production diversification. Attraction of investments. Growth of tax revenues due to a rising in the tax base. Reduction imports. Expansion the export potential of the chemical sector. Reduction budget costs for environmental activities through the production and sale of marketable products
Environmental	Reduction the negative impact of industrial waste by improving of waste management and the targeted use of local hydro-mineral resources
Innovative	Use of original innovative technical solutions that significantly reduce capital costs, increase the process efficiency and ensure the project's profitability

SDG-8 "Decent work and economic growth": 8.1 Ensure sustainable growth of GDP / GRP through modernization of production, development of innovations, increase of export potential, promote products with a high share of added value in foreign markets;

SDG-9 "Industry, innovation and infrastructure": 9.3.1. Increase sales of innovative products; 9.4. Stimulate the creation of technological innovations and innovative equipment of enterprises; 9.5. Ensure the provision of state financial assistance to enterprises with technological innovations to stimulate innovative activity;

SDG-12 "Responsible consumption and production": 12.4. Reduce the volume of waste generation and increase the volume of their recycling based on innovative technologies and production; 12.8. Taking advantage of the circular economy and closed supply chains;

SDG-17 "Partnerships for the goals": 17.1. Mobilize additional financial resources through the promotion of investment by foreign and domestic investors; 17.2. Develop partnerships between government and business to achieve the Sustainable Development Goals.

5 Conclusions

Sustainable development of the Dnipropetrovsk region is impossible without solving a critical environmental, social and economic problem of utilization of highly mineralized mine water in the Kryvyi Rih Basin.

In this work, we proposed and justified a pilot project that produces bromine and/or its compounds from mine water of Kryvbas. The project is based on the application of authors' innovative technical and technological solutions. Other advantages of the project include use of hydro-mineral and other local resources, improved waste management, environmental focus, import substitution and development of the region's export potential.

Implementation of the project will contribute to the achievement of sustainable development goals of the Dnipropetrovsk region, notably SDG-8, 9, 12 and 17.

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Rivers revitalisation: approaches to decision

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Abstract. The article is focused on the successful implementation of the global goals of restoring water objects in the context of sustainable development that is impossible without solving the regional problems of local watercourses and reservoirs reviving. It is emphasized that awareness of riparian spaces role as ecological corridors and importance of the healthy functioning of the river network through the revitalisation of even minor watercourses leads to growth attention to this problem in an increasing number of countries. On the example of the Slepiotka River in Katowice and Inhulets River in Kryvyi Rih the aspects, on which attention of revitalisation are accented in European countries and in Ukraine, are presented. In European countries, the basis for the approach to river revitalisation is their functioning as integral ecosystems. In Ukraine, nowadays, the main focus of river restoration is on cleaning them from silt sediment. In this article the approaches to decision of river revitalisation questions are presented. The main of them are: enhancing the ecological functionality of the watercourse as an ecosystem; providing flood protection; increasing the residential, cultural and recreational value; securing permanently sustainable use of watercourses and their river valleys.

1 Introduction

Nowadays science provides a better understanding of the extent to which our shared progress as human beings is undermined by the ways in which we have gone about achieving it, and too recognizes the Earth as a closely linked human-environment system. Science and technology in the modern time are powerful agents of change, depending on how and where they are headed. Increased science-policy-society cooperation can use achievement in our understanding of coupled human-environment systems and the shaping of innovative pathways towards achieving the ***Sustainable Development Goals***. The fact that a large number of countries are now incorporating science, technology and innovation in their national development agenda is a promising sign [1].

Governments can lead the transformation of the world's social, economic and environmental status towards universally beneficial outcomes when guided by the Sustainable Development Goals. But they must recognize that such transformation will involve tough choices and trade-offs. There is a growing tendency for governments and companies to invest in sustainable technologies. Over the past 10 years, at least 101 economies across the developed and developing world (accounting for more than 90 per cent of global GDP) adopted formal industrial development strategies, which increased opportunities for formulating new ways to promote innovations toward sustainable development. However, developing technology alone is not enough: technology must be made accessible and sufficiently attractive to encourage widespread adoption. Hence, in addition to research and development, the scaling up and the adoption of sustainable technologies are critically needed [1].

Understanding of an interconnection all the water resources of the Earth requires solving an issues of preservation and revival of not only the oceans and seas, but also a river network as a whole [2].

The situation of river spaces, especially of urban river spaces, in the European countries and in Ukraine, in the end of XX century, was in one sense very similar. In the context of industrialisation processes that occurred from the end of the 19th century through the first half of the 20th century, rivers and streams were used for sewage discharge, regulated and straightened for land reclamation and agricultural use, paved, channelled for flood protection (technical solutions) or even culverted. Areas by the riverside were often used commercially. Industrial zones and technical infrastructure such as roads or railway tracks were built in the floodplains. Large rivers were extended and used as waterways. During the second half of the 20th century riverside areas were subject to structural changes – industrial zones were partly abandoned, resulting in brownfields and deteriorated open spaces. Thus, up to the present day, urban river spaces suffer from lack of ecological functions (such as lack of habitat and biotope network function, lack of passability, contamination), lack of social functions (lack of accessibility of watercourses, lack of attractive open

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spaces next with water, inadequate perception of rivers by the public) and other problems.

With increasing awareness of role of riparian spaces as ecological corridors and areas for social activities, active protection and restoration of such areas has been recognized as a fundamental element of measures implemented to shape the special order and sustainable development of cities. Since the 1980s, awareness of ecological issue has risen, although at different speeds in western and eastern European countries. In the western countries revitalisation and renaturation rivers began in the 1980s whereas in the central European countries it did not commence until after 1990s.

In West Germany, since1980s an increasing number of river management projects have been developed and realised based on the insight that attention to ecological aspects of river maintenance does not hinder but can indeed play a role in improving flood protection [3, 4]. In the Eastern European countries Poland and Czech Republic, these processes did not begin until after the fall of the Iron Curtain. As for such countries as Ukraine – this practice is only beginning to appear [5, 6, 7]. Also, the potential recreational function of rivers is differently appreciating in the West and East.

In densely populated and industrialised areas, revitalisation of urban river areas contributes to a high quality of the environment as well as to a high quality of life. Urban river spaces are often the only functioning or potential reservoirs of biodiversity and open spaces in cities. Thus, the active protection and restoration of such areas is part of the repertoire of fundamental practices for shaping cities' spatial order and ***sustainable development***.

The ***aim of our work*** was a comparative analysis of approaches to river revitalization, which are used in the European Union countries and in Ukraine. As examples, the Slepiotka River in the Polish city of Katowice and the Inhulets River in the Ukrainian city of Kryvyi Rih were selected.

River revitalisation is not just about rivers. The preparation and implementation of a revitalization project is not limited to technical questions of hydraulic engineering but touches all aspects of sustainability.

Issues related to the restoration of river ecosystems can be considered from different angles. In our country, the revitalization is most often understood as a process of bottom dredging, which is necessary either for shipping purposes or in the context of the removal of contaminated sediments. Whereas in European practice much more attention is paid to restoring the hydrodynamics of the watercourse, the formation of characteristic ecotopes, as well as the recreational component.

The concept of revitalization was formulated by V. K. Khilchevsky [5, 6]: "This is the complete restoration of watercourses or certain sections thereof at the level of the river's existence, which preceded the industrial development of this region; when the river network was undisturbed and no centralized or point sewage discharges were made".

The issues of rivers revitalization in Ukraine at the state level are not yet considered comprehensively. The focus is on aspects such as dredging to improve shipping or the comprehensive programs for the elimination of consequences of flooding in the cities and towns of Ukraine. The latter is the Cabinet of Ministers of Ukraine resolution of 15.02.2002 No. 160.

In last years the processes of the bottom purification and dredging are activated in different regions of Ukraine. Cases of fragmentary manifestation of elements of modern river revitalisation are beginning to emerge at the level of urban communities. So, in Lutsk, elements of revitalization of the Saralaevka River – the right tributary of the Styr River was accomplished in 2013-2014 years [7]. The work was carried out on a small plot of 0,5 km in the central part of the city jointly by the city authorities and business structures. A revitalisation project consists of many different tasks and requires the cooperation of many different experts and also laypeople, who are convinced of the project`s success.

2 Objects and actions

Current planning methods in the European countries and in Ukraine have an impact on the implementation, realisation and acceptance of urban river revitalisation projects. Legal and technical regulations, generally available information and information provided by local, regional and state authorities as well as the development of planning criteria, the "planning philosophy" and the self-understanding of landscape architects and town planners all affect the outcomes of urban river revitalisation projects.

Below, the certain aspects and approaches to the revitalization of the Slepiotka River in Katowice and the Inhulets River in Kryvyi Rih are presented. We will consider the main points on which attention was focused in the projects, of which the author was a participant.

It is well known that the basis of large rivers water balance is a flow of small rivers. Small rivers hydrology, hydrochemistry, water quality is closely related to local geological-geomorphological, soil-plant conditions and anthropogenic processes that occur at a specific catchment. The formation of small rivers and their basins is determined by the surface runoff from regional landscape complexes, therefore an effect of natural and anthropogenic factors on such sites manifests faster and more clearly. It makes ecosystems of small rivers more vulnerable both a result of the direct impact on them of pollutants and indirect influence.

Transformation of Slepiotka River in Katowice. Katowice is a city in southern Poland, where in mid-18th century was discovered rich coal reserves. In the first half of the 19th century intensive industrialization transformed local workshops into industrial steelworks, mines, foundries. Now Katowice is a large coal and steel centre. For decades if not a century, in this region, rivers and streams were regulated and straightened for land reclamation and industrial use. They were paved or even tubed. For a long time, streams of all scales were adopted to discharge excess water and sewage. The regulation and channelisation of river beds, construction of drainage works and the implementation of active flood protection contributed to degradation of the river valleys.

The main goal of the revitalization action in Katowice was to recreate a blue-green river valley corridor in the highly urbanized, mid-part of Slepiotka River [8]. This particular stretch of the river was chosen for special, ecological and social reasons. The local catchment features numerous forms of land use and an advantageous land-owners structure, since most of the riparian area was municipal property. This river has quite suffered from the discharge of untreated sanitary sewage, but the flood risk was insignificant (figure 1). Additionally, it was located in the neighbourhood of a large housing estate in the direct Ochojec in the centre of Katowice. Access to the river and recreational facilities would improve the living conditions for thousands of inhabitants in the adjacent area. Thus, public support for the idea of revitalisation was high.

Fig. 1. Slepiotka River before transformation [8].

The authorities of Katowice city wanted to integrate the concept of a river corridor into special planning and management practices in post-mining urbanized areas, to re-establish a green axis along the river valley and to enlarge the public open leisure space. Furthermore, semi-natural wetland was to be created in order to increase the retention capacity and amphibious as well as water habitats and to establish a new paradigm for urban water management.

The revitalisation project on the Slepiotka River in Katowice is the opportunity to illustrate ways to implement the proposed transformation of the complete corridor of Slepiotka River. Not only did they want to increase the habitat diversity, establish a stable plant cover by using native plant species, and re-establish riparian forest, dry forest and wetlands habitat. They also aimed to show applications of soil bioengineering methods in order to establish buffer-zones that would protect the river from contaminations (figure 2).

The project included, among other things, the reconstruction of 210 m^2 of the dry old river bed and 950 m^2 of the wet old river bed, formation of a sand dune, construction of wooden bridges across the river and the old river bed, and setting-up of information boards.

The Slepiotka River action achieved several goals: The planned revitalisation was successfully implemented and the pilot action served as a very good starting point for preparation of the valley development plan. Most of the expectations of the City of Katowice and the researchers at the Central Mining Institute concerning revitalisation effects, development of habitat diversity and land use transformation were fulfilled. Moreover, the river corridor concept developed and tested in the pilot action area proved to be suitable for implementation along other parts of Slepiotka River and even at sites along other rivers.

Fig. 2. Slepiotka River after transformation [8].

Public involvement proved to be one of the most important aspects of the Slepiotka River revitalisation that had not been discussed previously. The City of Katowice as the coordinator of public participation and cooperation managed to involve numerous actors.

Besides city representatives, administrative partners included managers of the Slepiotka Valley, educational institutions as well as maintenance and safety services. Several universities and research institutes also participated in the partnership. Furthermore, the local community and private land owners from Slepiotka valley, NGOs, architects, artists, historians, and the media, among others, participated in workshops and meetings on the development of a long-term vision for the Slepiotka valley.

The workshops proved the potential of institutional, public, private and research-based cooperation and resulted in models of cooperation for the river valley partnership that increased the problem-solving competences by combining interests and ensuring the convergence of goals. Thus, public participation procedures helped to develop a coherent vision of spatial management for Slepiotka valley and led to overall satisfaction in the local community.

Riverbed purification in the Inhulets River in Kryvyi Rih. Kryvyi Rih is the largest iron ore mining and processing centre in Ukraine. The territory, where from narrow meridional strip 1,0–3,0 km wide and 100–150 km long, has mined 2,2–2,8 billion tonnes of chemically pure iron over the last 125 years [9]. Undoubtedly, long-term and large-scale man-made activity in this region has reflected on all components of the biosphere: lithosphere, atmosphere, hydrosphere. Technogenic origin products are constantly occur in compound of rivers sediment which flowing though this territory: particles of metallurgical slag, sludge, tailings of ore-dressing and other wastes. And the rivers look more like sewage gutter.

The accumulation of environmental problems and the consequent increase in community dissatisfaction has

prompted city authorities to seek solutions to the situation. At the same time, community awareness of the role of river valley as a network of environmental corridors and places of social activity was increased.

In 2014, the Dnipropetrovsk Regional Water Resources Administration entered an agreement with the private enterprise "Universalgasbud" for the implementation of the project "Anti-flood measures and improvement of the hydrological status of the Inhulets River in Dnipropetrovsk region".

The main purpose of the planned activities was implementation the Cabinet of Ministers of Ukraine resolution from 15.02.2002 No 160 "The comprehensive program for the elimination of consequences of flooding in the cities and towns of Ukraine". And also an implementation the regional program "The elimination of the effects of flooding the territory in cities and towns of Dnipropetrovsk region for the period till 2030" which was approved by the decision of the regional council of July 18, 2003 No 184-9/XXIV.

Among other works, significant of works were planned to clean up the Inhulets River in different parts of the Kryvyi Rih city. A project was planned to clear up 4,3 km of the riverbed and 0,5 km an old tributary of the Inhulets – the Saksahan River. Elements for a revitalization of the Inhulets River section and it tributary of Saksahan River, in the central part of the city in the park area, were implemented. The works included the riverbed purification, clearing the banks, arranging the territory (figures 3, 4). Sediment, removed from the river, was mainly deposited at landfills. The works which carried out in the city centre contained elements of revitalization, but the main goal was not done – to restore the flow of the river. The cleared areas are little flowing part of the riverbed.

Fig. 3. Works for purification of the Saksahan River [10].

The main goal of the second stage of works the riverbed purification in the Inhulets River (in 2017) was the removal of a large amount of contaminated sediment. Contaminated sediment was formed as a result of activity the ore-dressing factories and the metallurgical plant, which are located higher on the river flow. The initiative to carry out these works came from community of a nearby area.

During dredging and purification operations, a significant amount of subaquatic polluted and man-made transformed sediment was raised to the surface. A method of carrying out the cleaning operations included lifting of bottom silt in a semi-liquid state with the help of a dredge and burying it in ditches, which were located on the low bank of the river at a distance of 10-20 m from the river bank (figures 5, 6). The issues of storage and/or burial of the raised sediment are relevant and important, because it contains significant concentration of heavy metals, radionuclides and other pollutants.

Fig. 4. The intermediate stage of revitalisation project on the Saksahan River [10].

Fig. 5. Inhulets River. Stage of bottom purification (author' photo).

As you can see from the photo (figure 6), the ditches bottoms did not have any waterproofing, so in a short time a variety of pollutants (including heavy metals) can return end up in the river again. Also, there is a constant washing away of the upper soil layer, because after the backfilling of the ditches, phyto-recultivation works were not implemented.

3 Analysis and discussion

Thus, the features of the implementation of river revitalisation works of the Slepiotka River in Katowice and the Inhulets River in Kryvyi Rih were presented.

Environmental aspects and nature conservation have only gradually become incorporated into legal and regional programs; as a consequence, this contributes to reducing water pollution and tackling river revitalisation.

Fig. 6. Inhulets River. Ditch along the river which intended for burial of sediments (author' photo).

The main tasks of the revitalisation in European countries, and in Poland in particular, are questions of flow restoration, improved hydrodynamics, self-purification and ecosystems restoration. In the same time, the main goal of the revitalisation in Ukraine are still the issues of purification the riverbed from silt or questions relevant to preventing flooding. And on large rivers, the main problem of cleaning operations is the restoration of navigation. In rare cases, the purpose of revitalisation is to increase the recreational attractiveness of the territory (most often we are talking about the central areas of cities).

Waterfront areas, were often used commercially, start to using more and more as recreational zones. However, industrial zones and technical infrastructure such as roads or railways tracks, factories are staying in the floodplains. Even after industrial utilisation of inner-city began to decline, riparian post-industrial areas are still left abandoned. The visual and functional attractiveness of rives as well as the perceptibility of water courses are low. Public access to the river continues to be of little importance as are its ecological functions.

Here we will try to lay out main aspects of successful river revitalisation. One of the main aims of revitalisation addresses the enhancement of the ecological functionality of the watercourse. Secondly, river revitalisation is a means to implement flood protection. Onwards, it contributes to increasing the residential, cultural and recreational value of the area, and finally, it helps to secure the permanently sustainable use of watercourses and their flood plains.

From the experience such countries as Poland, Czech Republic and Germany [3, 4, 8, 11-14] and the own experience a participation in a some revitalisation projects [8, 9, 15] have been developed the following approaches for urban river revitalization. The approaches are intended to help planners, decision-makers, executing authorities and stakeholders consider the wide range of aspects (ecological, economic and social) relevant to the specific requirements of river revitalisation in an urban environment. The approaches are divided into four basic groups which are shown on the scheme (figure 7). Each of these four basic components consist of a range of issues.

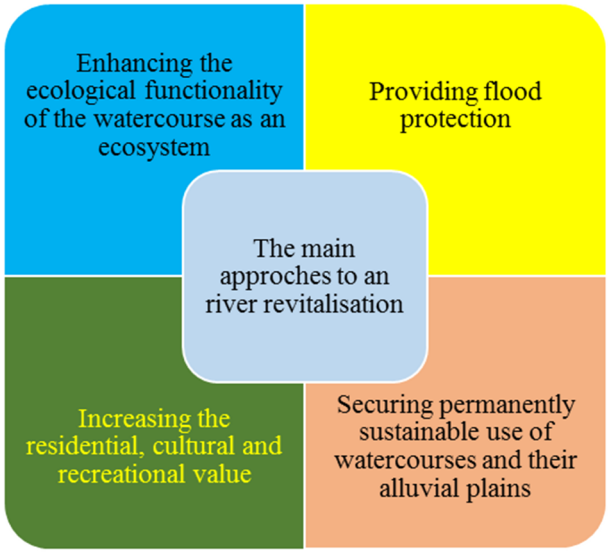

Fig. 7. The scheme of an approaches to a river revitalisation.

Enhancing the ecological functionality of the watercourse as an ecosystem can include next aspects:

- Renewal the hydrodynamic regime of watercourses. It can be achieved by increase the morphological diversity of the riverbed as well as the discharge diversity and its dynamics; by modify of the sediment regime through a suitable longitudinal profile of the watercourse.
- Renewal minor watercourses can be done by to remove the channeled underground stretches of the watercourses and prevent further channeling; by deepening a shallow section of riverbeds; if possible, by re-meander straightened river beds in minor watercourses, according to their historical development.
- Improve the water quality can by support the self-cleaning capacity of watercourses; by addition water infrastructure (build separated sewer systems, wastewater treatment plants); by pre-treat rainwater before it reaches the river. One of the main solutions – to eliminate pollution sources.
- Increase the biodiversity of the biotopes in river valley can achieved by improve local habitats according to the local conditions of each river valley; by remove invasive plant species; by support the reintroduction of native plant species and habitats.
- Assurance migration permeability of watercourses can be achieved by build fish passes; by provide migration permeability by transversal objects (stepped weirs and chutes), and technical alterations (shallow water column and high flow speed) to the watercourse.
- Need to give an advantage nature-like adaptations over technical modifications to the landscape.

Providing flood protection can include next aspects:

- Mitigation the risk of flood damage with help: adopting the idea that rivers need more space; need to

avoid artificial elevation of terrain due to building development in active flood zones.

- Increase the retention capacity of the landscape can be achieved by allow the natural overflow of rivers into the alluvial plains; need to renew and create wetlands, where it is possible; to implement elements of the systems of ecological stability.
- Reducing direct outflow from the drainage area (especially important for small watercourses) by the increase the rate of rainwater infiltration in the area by allow its infiltration into the soil profile; reuse excessive rainwater in households and the municipal sector.
- Implementation technical measures to catch extreme flow rates: use retention tanks and dry polders in the river valley.

Increasing the residential, cultural and recreational value may be consist of next elements:

- Incorporate water into the city's image as a major landscaping feature of the urbanised space. So, we can use the alluvial plains as significant urban spaces with a unique potential for recreation and leisure.
- Access to the water as a security and pleased moment to leisure: building play facilities providing interaction with the water element; provide possibilities for fishing; allow direct public access to the watercourse in some places where it is safe and possible.
- Creation sport and recreational paths (greenways) along watercourses. Creation or combination paths for pedestrians, cyclists, in-line skaters and other non-motorised users, following the terrain in the alluvial plains. Improve a connection of the city with the surrounding landscape
- Building sport and recreational facilities in the alluvial plains. Creation places for short-term recreation of the public along the sport and recreational paths.
- Ability to provide supplementary infrastructure. Building an information system along the sport and recreational paths (signposts, information boards, panels along educational paths providing information about natural and cultural features and values in the area). Installation street furniture; presentation artefacts and temporary exhibitions.

Securing permanently sustainable use of watercourses and their river valleys can be achieved:

- By improving the applicability of the land use planning process in terms of flood control and watercourse protection. Need to use the instrument of land use planning to apply the above-mentioned principles in the revitalisation of watercourses in urbanized areas. Need to develop more detailed rules for the use of built-up areas concerning the risk of potential.
- Set rules for water withdrawal to secure a sufficient flow volume for maintaining the dynamic water regime of watercourses.
- Minimise conflicts with infrastructure (bridges, roads, pipelines).

Main steps of successful river revitalisation include: planning (with all stakeholders' involvement), implementation, scientific and educational compound, public relations activities and financing.

Planning. It is very important to consider the aims and requirements of sectoral planning (especially plans and regulations of the water management authorities, nature conservation management authorities and land use management authorities) and of spatial planning and include the revitalisation project in these aims. So need to have the revitalisation project incorporated into the relevant region and local spatial management plan, especially if the project is not limited to a single site but will affect the whole course of a river or a creek within the city or urban spaces with adjacent river banks and flood plains. In this way the project will be protected authorities and will have to be taken into account in subordinate planning. Additionally, an environmental impact assessment might be required. On the figure 8 a planning model of the river revitalisation is introduced.

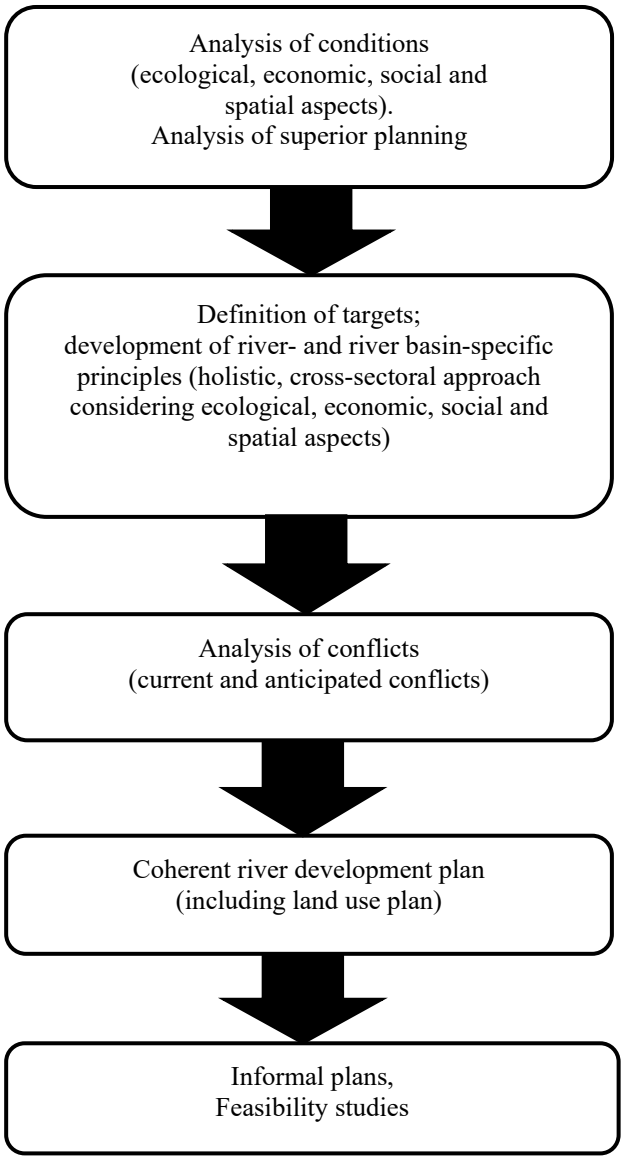

Fig. 8. Scheme of planning the river revitalisation activities.

Furthermore, improving the availability, visibility, attractiveness and safety of riverside areas has to be incorporated into the revitalisation project; secure access to the water and continuity of waterside routes should also be ensured. Waterfronts are socially as well as

economically important determinants of a city's attractiveness.

A combination of necessary (flood protection) and desirable activities fosters public and also political acceptance of urban river revitalisation measures.

Implementation. Preferable, start revitalisation of a river or stream from the upper reaches downstream. Otherwise, the current emerging from a paved stretch and encountering the stronger coarseness of a renaturated stretch may develop strong erosive forces and require comprehensive pavements in the transition area. Upstream drainage conditions always determine the flood prevention measures in the territory considered for revitalisation.

The surveys of the project area must be thorough and qualified. Need to eliminate sources of pollution in the catchment area as a precondition for proper revitalisation and increase the self-cleaning capacity of water bodies. Ensure that construction is supervised with respect to ecological issues so that the goals are met.

Take a priority bio-engineering measures rather than technical solutions.

Scientific and educational compound of the river revitalization project and public relations activities. A prerequisite for a successful project should be a comprehensive study of the ecology of the river. Attracting educational institutions will help not only to collect the necessary information, but also increase the knowledge of schoolchildren and students about the features of the region. It is possible to provide an implementation public education programs and improve training in revitalisation principles that target different social groups.

A significant role is efforts to secure positive media coverage and public perceptions of the project by implementing an on-going information campaign for the project. Remember to use always the same logos and graphic design. It is very important to promote the project and its benefits by organizing events, celebrations, ground-breaking ceremonies, inaugurations, guided tours, leaflets, press relations, exhibitions, display boards, etc. Raise awareness of the manifold benefits of revitalisation project promotes successful implementation of it. So it is important to disseminate information about good and best revitalisation practices examples among decisionmakers and the general public.

Financing. Including solutions to water management tasks in the revitalisation project makes its funding and implementation more likely.

It is important to respond quickly to available funds is a frequent experience in public administrations, as payments from environmental impact mitigation regulation or other fees may suddenly become available or funds have to be spent before the fiscal year ends.

Endeavour to find adequate co-financing, because the municipal budget is characterised by fundamental restrictions in many places. Analyse opportunities for dividing the project into several stages that are realised step-by-step and financed from different sources. Obtain information on possible grants from various sources. Find institutions (sponsors) that are able to make a permanent contribution to the project, even if it is small (particularly during maintenance). Use impact mitigation regulation / impact mitigation fees to finance revitalisation projects. Explore possibilities for private funding (e.g. foundations, Private-Public-Partnerships, sharing costs with private developers).

Try to consider the costs as completely as possible in order to avoid miscalculation. Budget enough funding to allow for good planning and maintenance. A river revitalisation project can be sustainable only if the investment is well prepared during the planning phase and if future maintenance is assured. Try to reduce maintenance costs. Maintenance costs can get expensive and are often not taken into account at the start of a project. Factor in enough funding to cover unforeseen minor and major changes during the construction work. Calculate enough funding to provide adequate resources for public participation.

4 Conclusions

1. The successful implementation of the global goals of restoring the Earth's water objects in the context of sustainable development is impossible without solving the regional problems of local watercourses and reservoirs reviving. Awareness of riparian spaces role as ecological corridors and areas for social activities and also of the importance of the healthy functioning of the river network through the revitalisation of even minor watercourses leads to growth attention to this problem in an increasing number of countries. Ukraine, as an integral part of the world community, is striving to restore its water resources and revive rivers.

2. Current approaches to solving the problem of river revitalization have their differences in different countries. These differences are based on the purpose of using a watercourse. In European countries, the basis for the approach to river revitalization is their functioning as integral ecosystems. The result of this approach is an attempt to maximize the restoration of the river to it natural state, minimize the anthropogenic pressure, harmonize the relationship between people and nature. In Ukraine, today, the main focus of river restoration is on cleaning them from silt sediment. At the same time, the following goals are being pursued: of an economic nature – the restoration of river navigation; flood control measures; solving a number of environmental problems. However, the latter are often not prioritized and, as a result, the real tasks of restoring hydroecosystems are not fully resolved.

3. Based on the analysis of participation experience in various river revitalization projects, the main approaches to solving this problem are presented and characterized: 1) Enhancing the ecological functionality of the watercourse as an ecosystem; 2) Providing flood protection; 3) Increasing the residential, cultural and recreational value; 4) Securing permanently sustainable use of watercourses and their river valleys. The main stages of the implementation of river revitalization projects, especially in urban areas, are presented, and ideas are proposed for a comprehensive consideration of emerging problems.

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Macronutrients and heavy metals contents in the leaves of trees from the devastated lands at Kryvyi Rih District (Central Ukraine)

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Abstract. This research was performed at Petrovsky waste rock dump, the Central part of the Kryvyi Rih iron-ore & metallurgical district (Dnipropetrovsk region, Ukraine). The macronutrients (K, Ca, Mg, P and S) and heavy metals (Fe, Mn, Zn, Cu, Pb and Cd) contents in the leaves of three species of the trees (Ash-leaved maple, Silver Birch and Black locust) that were collected on devastated lands were assessed. It was established that trees which grow on the Petrovsky dump take place under evident shortage of nutrients (especially K and P) and excess of metals (especially Fe, Mn and Zn). It is revealed that Ash-leaved maple and Black locust are more resistant to the geochemical conditions of devastated lands. In this regard, these species of trees can be recommended for forest restoration & reforestation on devastated lands.

1 Introduction

Devastated lands, formed as a result of human activity, occupy vast areas: more than 2,000,000 ha worldwide, about 200,000 ha in Ukraine and about 100,000 ha in Germany [14, 16, 21]. These lands are as pollution sources for the atmosphere, soil, surface water. They are also sources of distribution of weeds [7, 22, 23]. Therefore, devastated lands pose a serious threat to human well-being. Currently, planting trees is the most promising way of restoring devastated lands [1, 19]. However, on these lands the ecological conditions are very strict for trees [7, 21, 18, 22, 31]. Therefore, investigation of chemical composition of trees that naturally grow on devastated lands is very important.

The object of this work: to carry out a comparative analysis of macro nutrients and heavy metals contents in the leaves of trees spontaneously sprouting on the devastated lands at the Kryvyi Rih District.

2 Materials and methods

The results of the studies, which were carried out at Petrovsky waste rock dump (Fig. 1) in Central part of the Kryvyi Rih District (Dnipropetrovsk region, Ukraine), were used as the materials for this paper.

Petrovsky waste rock dump was formed for storage: 1) low-prospective iron ores, 2) quartzites 3) shales 4) loose rocks (clay, sand and loam). On this dump the ecological conditions for growth and development of woody plants are typical for Kryvyi Rih region [7]. It is based on the structure of mine rocks, dump's age (about 50 years) and dump's area (26 ha). Territories located for 30 km apart from industrial facilities and stationed in Gurovsky forest were used as control site.

Sampling of leaves from three species (Ash-leaved Maple *Acer negundo* L., Silver Birch *Betula pendula* Roth. and Black Locust *Robinia pseudoacacia* L.), drying and grinding of them were performed in the fall of 2019 by classical methods [5, 10, 11, 24].

For the sample preparation, to the leaf sample weight of 100 mg 0.2 ml of H_2O DI and 1.6 ml of HNO_3 (65%) were added. The solution was incubated at room temperature during 24 hours. Then, 0.6 ml of HF (4.8%) and 0.9 ml of HCl (36%) were added to this solution. Subsequently, the solution was placed in the microwave oven (Mikrowellen-Laborsystem, MLS-ETHOS plus). The microwave exposure was continued during 2 hours. Next, H_2O DI was poured into, diluting the volume of solution to 10 ml. Finally, 0.1 ml of Internal Standart was poured to 1 ml of mineralizate collected, after which H_2O DI was poured again diluting the volume to 10 ml.

The final determination of macronutrients (K, Ca, Mg, P, S) and heavy metals (Fe, Mn, Zn, Cu, Pb, Cd) concentrations was performed using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS X-Series instrument 2, Thermo Fisher Scientific, USA).

The analytical part of our research was performed on laboratory base of the Institute of Biosciences, Freiberg Mining Academy and University of Technology (Freiberg, Germany).

The obtained results of macronutrients and heavy metals content in the leaves of trees were calculated in $mg*kg^{-1}$ of dry weight ($mg*kg^{-1}$ d.w.). Then the results were processed by standard methods of variational

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statistics at the significance level of $p < 0,05$ [17].

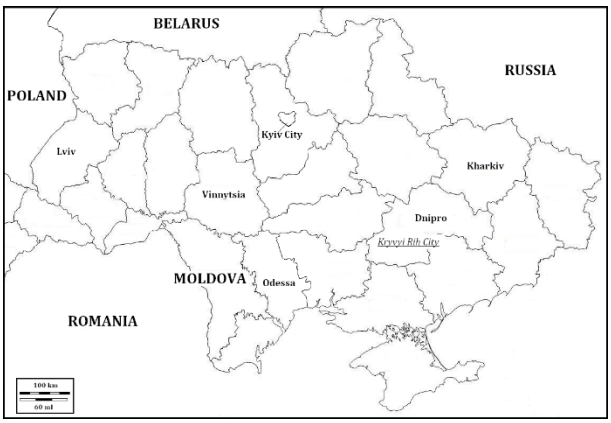
3 Results

3.1 Macronutrients and heavy metals content in leaves at a control site

According to scientific literature [6, 8, 9] the Potassium average content in plants is in the range from 7 500 to 15 000 mg*kg^{-1} d.w. We found that in a control site the values Potassium concentration in the leaves of Birch and Black locusts leaves were below these this range. While, in the maple leaves Potassium concentrations were appeared to be within this range (Table 1). The average Calcium concentrations in plants are from 12 500 to 18 000 mg*kg^{-1} d.w. [6, 8, 9, 12]. By the results of our research, Calcium content in the Birch leaves is within this range, while in the leaves of Black locust and Maple the examined value is above this limit. The analysis of scientific literature shows, Magnesium contain in the plants is 1 000-3 200 mg*kg^{-1} d.w. [6, 8, 9, 12]. At a control site, the Magnesium concentrations in the leaves of all of three tree species slightly exceeded the values of the range pointed above.

The average concentrations of Phosphorus in plants are 1 750-2 300 mg*kg^{-1} d.w. [6, 8, 9, 20]. Phosphorus content in the leaves of all of tree's species at control site is below the values of this range. According to the scientific literature [6, 8, 20], the average Sulfur content is from 7 500 to 14 000 mg*kg^{-1} d.w. We found that in control territories the Sulfur concentrations in the leaves of all the trees were below the values of this range (Table 1).

Thus, the Calcium and Magnesium content in the leaves of trees from a control site is within the average values established for all the vegetation. In our opinion, this phenomenon may be due to the regional biogeochemical features of Kryvyi Rih iron-ore & metallurgical district. As it is well known, in this region, the increased content of these macronutrients was detected in all the objects of Nature: soil, groundwater and surface water.



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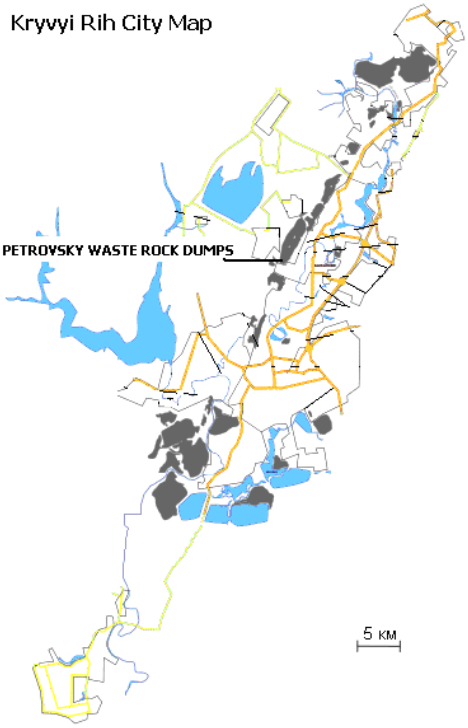

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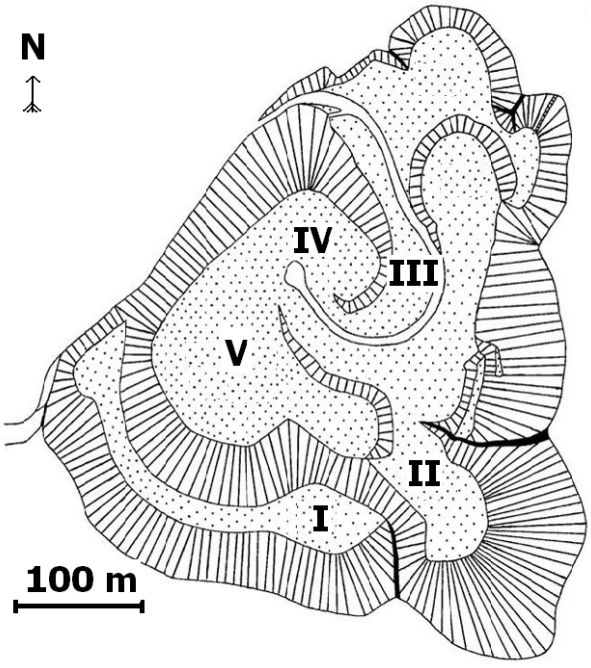

Petrovsky Waste Rock Dumps Map

Fig. 1. Location of study areas (I, II, III, IV, V – Study Plots)

Phosphorus and Sulfur concentrations in the leaves of trees from a control site were below the range values of these elements in all vegetation. This consistent pattern can be explained by the seasonal dynamics of nutrients concentration in the leaves of trees.

Average Ferrum content in all vegetation is 200 mg*kg^{-1} d.w., while in the leaves of trees that have grown outside by influence of industrial enterprises this metal content is 150-350 mg*kg^{-1} d.w. [2, 9, 12]. At a control site the Ferrum content was found at the same

interval in the leaves of Birch and Black locust. Whereas, in the leaves of Maple a Ferrum concentration was slightly higher than this interval values (Table 2).

Table 1. Macronutrients content in the leaves of trees from a control site.

Species of trees	Macronutrients content, mg*kg^{-1} of dry weight		
	M	m	CV%
Potassium			
Ash-leaved maple	10 110	192,09	28,46
Silver birch	4 633	184,00	21,41
Black locust	4 287	98,60	18,52
Calcium			
Ash-leaved maple	17 610	1232,70	29,41
Silver birch	13 830	1244,70	22,29
Black locust	19 240	1539,20	25,47
Magnesium			
Ash-leaved maple	3 589	260,20	29,12
Silver birch	2 780	201,69	31,22
Black locust	3 276	230,01	21,78
Phosphorus			
Ash-leaved maple	939,10	79,93	35,41
Silver birch	1065,00	86,48	38,45
Black locust	1042,00	95,18	32,25
Sulfur			
Ash-leaved maple	846,00	68,61	29,54
Silver birch	650,20	64,37	26,75
Black locust	933,10	83,05	21,56

M – arithmetic mean, m – standard error of mean, CV% – coefficient of variability.

Table 2. Heavy metals content in leaves of trees from the control site.

Species of trees	Macronutrients content, mg*kg^{-1} of dry weight		
	M	m	CV%
Ferrum			
Ash-leaved maple	521,10	32,26	29,41
Silver birch	301,70	21,79	26,89
Black locust	304,10	12,86	21,85
Manganese			
Ash-leaved maple	87,16	4,97	24,63
Silver birch	81,66	4,82	22,35
Black locust	45,49	2,64	29,54
Zinc			
Ash-leaved maple	7,22	0,09	30,41
Silver birch	44,55	1,86	32,85
Black locust	9,50	0,20	31,45
Copper			
Ash-leaved maple	1,46	0,07	25,54
Silver birch	2,35	0,15	29,56
Black locust	1,38	0,05	28,75
Lead			
Ash-leaved maple	0,210	0,023	31,44
Silver birch	0,165	0,018	36,85
Black locust	0,129	0,014	35,78
Cadmium			
Ash-leaved maple	0,007	0,002	30,29
Silver birch	0,031	0,006	31,77
Black locust	0,003	0,001	32,45

M – arithmetic mean, m – standard error of mean, CV% – coefficient of variability.

The average Manganese content in all vegetation is 200 mg*kg-1 d.w. [9, 12, 20]. We found that at a control site in the leaves of all tree species, the concentrations of this metal were well below than this range. Zinc concentrations in vegetation are around 30 mg*kg-1 d.w., and in the leaves of trees that have grown outside by industrial enterprises influence, they are at range 25-50 mg*kg-1 d.w. [8, 9, 12, 20]. According to our research, Zinc content in Birch leaves is within the same range. It should also be noted that the concentrations of this metal in the leaves of Black locust and Maple were significantly lower (Table 2).

In the Vegetation of the World, the average Copper contain is about 8 mg*kg^{-1} d.w. [9, 12, 20]. We found that the concentrations of this metal in the leaves of all tree species were significantly below this level. Average Lead content in the vegetation is around 1,25 mg*kg^{-1} d.w. [9, 12], and in the leaves of trees it is at the level of 0,5-1,0 mg*kg^{-1} d.w. [12, 20]. The analysis of obtained results shows that at a control site the concentrations of this metal in the leaves of all the investigated tree species were below these values (Table 2)

The similar consistent patterns were found for Cadmium concentrations. In all the vegetation its content is 0,03-0,05 mg*kg^{-1} d.w. At a control site, the concentrations of this metal in the leaves of all the tree species were below these values (Table 2).

Thus, at a control site in the leaves of the trees, the only Ferrum and partially Zinc concentrations lie within the range of average values established for the vegetation. While, the concentrations of other metals (Manganese, Copper, Lead and Cadmium) are 2-7 times lower than the average values. In our opinion, this phenomenon can be explained by the effect of regional geochemical and biogeochemical anomaly, which is characterized by the increased content of Ferrum and Zinc. In addition, we believe that casual autumn dynamics of chemical elements in plants has the effect on the concentration of heavy metals in the leaves of trees.

3.2 Macronutrients and heavy metals content in leaves at a devastated lands

In the devastated lands at Kryvyi Rih iron-ore & metallurgical district, the content of Potassium in the leaves of the trees is less than control values (Fig. 2).

We found that, in the leaves of trees from the devastated lands at Kryvyi Rih region Potassium concentrations were less than the control values in Maple – by 15-70% ($p < 0,05$), in Birch – by 15-55% ($p < 0,05$). In the leaves of Black locust, both potassium content reduction (plots II III – by 10-45% ($p < 0,05$) less) and accumulation of this element (plots IV – by 20% ($p < 0,05$) higher) were detected.

Calcium content in the leaves emerged below than control values too (Fig. 2): in Birch – by 19-54% ($p < 0,05$) and in Black locust – by 51-62% ($p < 0,05$). It should be noted that the concentrations of this metal in Maple's leaves at the plots II, IV, V were at the level of control values, while at the plot III they were by 40% ($p < 0,05$) less than the control values (Fig. 2).

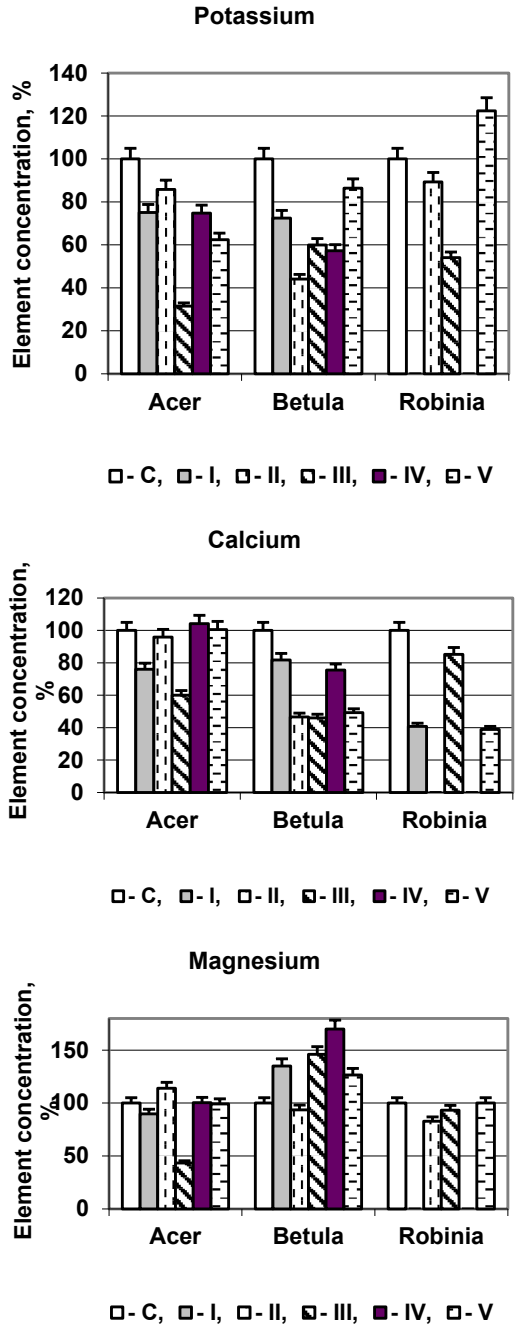

Fig. 2. The relative K, Ca, Mg content in the leaves of trees from the devastated lands at Kryvyi Rih district. The element content in the control is 100%. Research areas: C – control, I, II, III, IV, V plots on devastated land. Acer – Ash-leaved maple, Betula – Silver Birch, Robinia – Black locust.

The analysis of obtained results (Fig. 2) shows that the Magnesium content was both higher and lower than the control values. Thus, in the leaves of Birch the accumulation of this element is predominant, the excess of control values is by 25-70% ($p < 0,05$). In Maple's leaves, Magnesium concentrations at plot II were by 14% ($p < 0,05$) above control and at plots I and III they were 10-55% ($p < 0,05$) less than control values. The content of this element in Black locust's leaves was within the control values (plots II and V) or by 17% ($p < 0,05$) less (plot II).

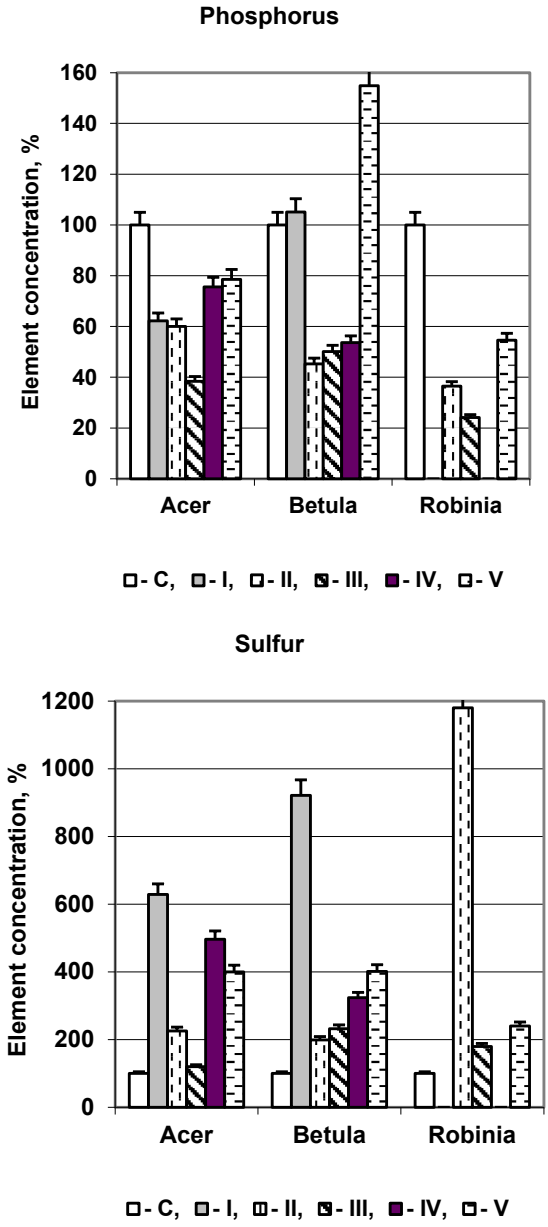

Fig. 3. The relative P и S content in the leaves of trees from the devastated lands at Kryvyi Rih district. The element content in the control is 100%. Research areas: C – control, I, II, III, IV, V plots on devastated land. Acer – Ash-leaved maple, Betula – Silver Birch, Robinia – Black locust.

It was found that the Phosphorus content in the leaves of trees from devastated lands at the Kryvyi Rih region was less than control values (Fig. 3): by 21-61% ($p < 0,05$) for Maple and by 46-63% ($p < 0,05$) for Black locust. The content of this element in the Birch's leaves in most cases (plots II, II, IV) was below the control values by 44-54% ($p < 0,05$), but at the plot V it emerged by 55% ($p < 0,05$) higher than the control value.

The analysis of obtained results shows that in the leaves of trees from the devastated lands at Kryvyi Rih region only accumulation of Ferrum is statistically significant (Fig. 4). Thus, the concentrations of this metal in the leaves were higher than the control values: in Black locust by 1,7-2,4 times ($p < 0,05$), in Birch by 1,9-4,0 times ($p < 0,05$), in Maple by 1,2-5,0 times ($p < 0,05$).

Manganese content exceeds the control values in Black locust leaves (by 2,7-8,1 times ($p < 0,05$)) and in Birch (by 13-49 times ($p < 0,05$)). While, in the Maple leaves, both accumulation of this metal (at plots I and II by 1,5-1,7 times above the control ($p < 0,05$)) and its "leaching" (at plots III and IV by 15-19% below control ($p < 0,05$)) were found.

In most cases, the Zinc contents in the leaves of trees were higher than the control values: by 11-19% ($p < 0,05$) in Maple, by 1,4 times ($p < 0,05$), in Black locust and 1,7-3.2 times ($p < 0,05$) in Birch. It was also found that at plot III concentrations of this metal were below the control values: in Maple by 37% ($p < 0,05$) and in Black locust by 48% ($p < 0,05$).

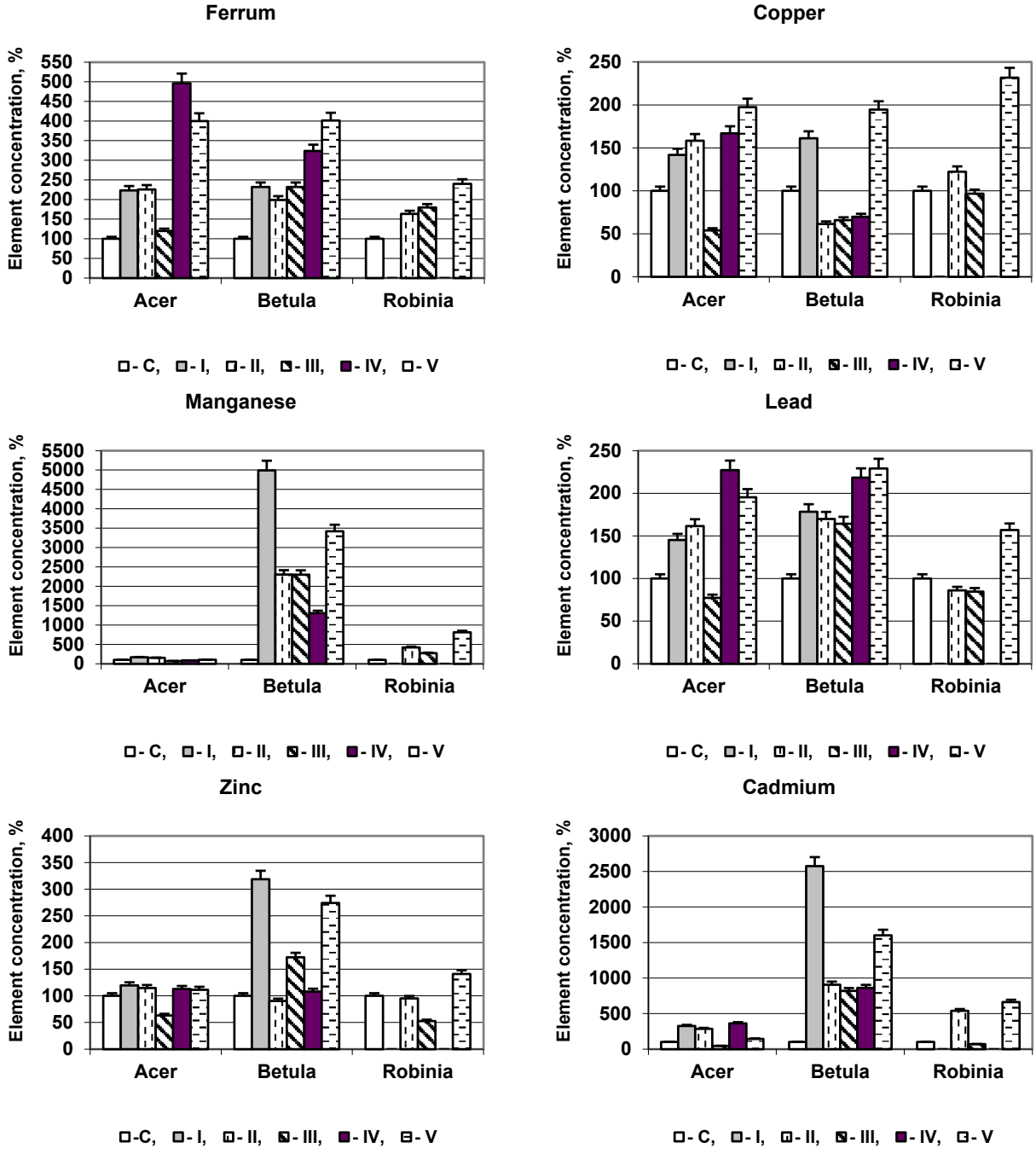

Fig. 4. The relative heavy metals content in the leaves of trees from the devastated lands at Kryvyi Rih district. The element content in the control is 100%. Research areas: C – control, I, II, III, IV, V plots on devastated land. Acer – Ash-leaved maple, Betula – Silver Birch, Robinia – Black locust.

It is established that only Copper accumulation was statistically significant in the leaves of Black locust. The concentration of this metal was by 1,2-2,3 times ($p < 0,05$) above the control values. In the leaves of other tree species both high and low Copper content were detected. Thus, the concentrations of this metal exceed the control values: by 1,4-2,0 times ($p < 0,05$) at plots I, II, III and V in Maple, by 16,9 times ($p < 0,05$) at plots I and V in Birch. At the same time, the Copper content in the leaves was lower than the control values: by 46%

($p < 0,05$) at plots III in Maple, by 31-39% at plots III and IV in Birch.

Our findings (Fig. 4) show that Lead concentrations in Birch leaves at all the plots were higher than the control values by 1,6-2,3 times ($p < 0,05$). In Maple leaves at plots I, II, IV and V this metal's concentrations were also higher than control values, by 1,5-2,3 ($p < 0,05$). But at plot III the Lead content was below than control by 23% ($p < 0,05$).

In Black locust leaves, this metal accumulation was detected only at plot V, where its content was 1,6 times higher than control ($p < 0,05$). At the same time at plots III and IV, the Led concentrations were below than control values by 14-16% ($p < 0,05$).

Cadmium content in the leaves of woody plants exceed the control values: by 9-25 times ($p < 0,05$) in Birch, by 5,4-6,6 times ($p < 0,05$) in Black locust and by 5,4-6,6 times ($p < 0,05$) in Maple. It should also be noted that at plots III, the concentration of this metal is below the control values in the leaves of Maple and Black locust a, respectively by 32% and 45% ($p < 0,05$).

4 Discussions

All macronutrients that we have studied (K, Ca, Mg, P, and S) are biologically significant chemical elements. Therefore, these elements have a significant influence on all the important processes of life, growth and development of woody plant species [5, 12, 15]. In the course of evolution, for each chemical element, a certain interval of optimum was formed. The information about this interval is very important for the biological evaluation of the element content [8, 9].

According to scientific publications, the optimal Potassium concentration in plants is from 10 000 to 14 000 mg*kg^{-1} d.w., while the content of this element exceeding 25 000 mg*kg^{-1} d.w. is considered as phytotoxic [6, 8, 9, 20]. According to the results of our research, at a control site in the leaves of Black locust and Birch, the Potassium concentration was below the biological optimum (4 200-4 700 mg*kg^{-1} d.w.). The content of this metal in the leaves of Ash-leaved maple was slightly higher (about 10 000 mg*kg^{-1} d.w.), but it was at the lower level of biological optimum.

On devastated lands at Kryvyi Rih iron-ore & metallurgical district, the Potassium concentration ranges from 200 to 870 mg*kg^{1} d.w., which is much less than the values of biological optimum. This is undoubtedly indicative of a deficiency of Potassium content for these plants.

The average optimal Calcium concentration in plants is between 10 000 and 20 000 mg*kg^{-1} d.w., and its phytotoxic amount is over 40 000 mg*kg^{-1} d.w. [6, 8, 9, 20]. At the control site, the concentration of this element was within the biological optimum. On devastated lands, the growth and development of woody plants occur with some deficiency of this macroelement. The Calcium concentration in Birch leaves is 6 400-11 300 mg*kg^{-1} d.w., in Black locust leaves is 7 800-16 400 mg*kg^{-1} d.w.

The average Magnesium concentration in plants actually coincides with the range of biological optimum (1 000-3 200 mg*kg^{-1} d.w.), and the phytotoxic concentration is more than 5 500 mg*kg^{-1} d.w. [6, 8, 9, 20]. According to the results of our studies, the content of this metal in the leaves of trees at the control site is near the upper limit of the biological optimum (2 800-3 600 mg*kg^{-1} d.w.), but does not exceed the threshold of its phytotoxicity. On devastated lands, the Magnesium concentration in the leaves of trees in most cases was above the upper limit of the biological optimum (3 200 mg*kg^{-1} d.w.) but was below the phytotoxicity threshold (5 500 mg*kg-1 d.w.).

According to scientific publications, the optimal Phosphorus concentration in plants is 1 000-3 000 mg*kg^{-1} d.w., the content of this element greater than 5,000 mg*kg-1 d.w. is considered as phytotoxic [6, 8, 9 20]. We found that at the control site the Phosphorus, content in the leaves of trees was at the minimum level of its biological optimum 950-1 500 mg*kg^{-1} d.w. On devastated lands, in most cases, its concentration was much lower than the values of the biological optimum 350-750 mg*kg^{-1} d.w. This fact indicates a deficit of this macronutrient.

The range of biological optimum for Sulfur content in plants is 1 500-2 500 mg*kg^{-1} d.w. and the phytotoxicity threshold is greater than 5 000 mg*kg^{-1} d.w. and [6, 8, 9 20]. We found that at a control site in the leaves of trees, the Sulfur content was below the values of the biological optimum (650-950 mg*kg^{-1} d.w.). On devastated lands, in all cases, the Sulfur concentration in the leaves of trees was higher than control. However, the content of this element, with rare exceptions (Black locust at plot II), was in the range of biological optimum and did not exceed the phytotoxicity threshold.

According to the scientific literature [3, 12, 13, 27], 100-250 mg*kg^{-1} d.w. Ferrum concentration in plants is considered optimal, and the phytotoxicity threshold is 500-550 mg*kg^{-1} d.w. We find that woody plants in all study areas contain extremely high concentrations of Ferrum in leaves: 300-500 mg*kg^{-1} d.w at a control site and 650-2010 mg*kg^{-1} d.w at devastated lands. Therefore, it can be assumed that woody plants are clearly exposed to the phototoxic effects of high concentrations of this metal.

Manganese content in plants from 50 to 200 mg*kg^{-1} d.w. considers as optimal, and if metal content is more than 300-400 mg*kg^{-1} d.w. a stable phytotoxic effect was observed [3, 10, 12, 29]. We found that at a control site a Manganese concentrations in the leaves of trees for all species was in the optimality range – 50-90 mg*kg^{-1} d.w. On devastated lands, the content of this metal in the Maple's leaves was slightly higher than the control values (70-170 mg*kg^{-1} d.w.), but does not go beyond the optimum. While, the Manganese concentrations in Black locust's leaves and in Birch's leaves significantly exceed the toxicity threshold (300-800 and 2300-5000 mg*kg^{-1} d.w., respectively). Hence, the plants are influenced by Manganese phytotoxicity.

For Zinc, the optimum range of its content in plants is 10-50 mg*kg^{-1} d.w. and its phytotoxicity threshold is 100 mg*kg^{-1} d.w. [10, 12, 26, 30]. According to our studies results, the concentrations of this metal in the leaves of Maple and Black locust were in the optimum range (both

at the control site and on the devastated lands (except for plot V)). In Birch leaves, Zinc concentrations reach 100-280 mg*kg^{-1} d.w., which actually exceeds the phytotoxicity threshold.

Data from scientific publications indicate that Copper concentrations in plants of 5-10 mg*kg^{-1} d.w. are maintained optimal, and the phytotoxical threshold is greater than 20 mg*kg^{-1} d.w. [3, 11, 25, 26]. The results of our studies have shown that the concentrations of this metal in the leaves of all three tree species do not exceed the lower threshold of the optimum zone: at a control site – 1,4-2,4 mg*kg^{-1} d.w. and at devastated lands – 0,8-4,6 mg*kg^{-1} d.w. Therefore, we can assume that there is a deficiency of this important trace element.

The biological optimum range for Lead concentration in plants is 5-10 mg*kg^{-1} d.w., and the phytotoxical threshold is 30 mg*kg^{-1} d.w. [4, 11, 13, 20]. We have found that the content of this metal in the leaves of trees does not exceed the minimum value of the biological optimum: 0,13-0,21 mg*kg^{-1} d.w. at the control site and 0,1-0,48 mg*kg^{-1} d.w. at devastated lands.

According to scientific publications, the optimal Cadmium concentration in plants is 0,005-0,020 mg*kg^{-1} d.w., the content of this element greater than 0,200 mg*kg^{-1} d.w. is considered as phytotoxic [3, 10, 25, 28]. We found that at a control site, the content of this metal in the leaves of all three species was within the optimum range: 0,0029-0,0306 mg*kg^{-1} d.w. At devastated lands, Cadmium concentration was also in the optimum range for Maple (0,0103-0,0234 mg*kg^{-1} d.w.) and for Black locust (0,0029-0,0200 mg*kg^{-1} d.w.). For Birch leaves, the content of this metal in all cases exceeds the values of the phytotoxicity threshold 0,2508-0,4897 mg*kg^{-1} d.w.

Among the woody plants species that we have investigated, the maximum concentrations of macronutrients have been identified in Black locust and Ash-leaved maple. The maximum concentrations of heavy metals were found in the Silver birch.

5 Conclusions

Macronutrient (K, Ca, Mg, P, S) and heavy metals (Fe, Mn, Zn, Cu, Pb, Cd) contents in leaves of three tree species indicate a difficult ecological conditions on the Petrovsky waste rock dump devastated lands at the Kryvyi Rih iron-ore & metallurgical district. The growth and development of trees on these devastated lands is carried out with a clear nutrient's shortage (especially K and P) and metal's excess (especially Fe, Mn and Zn).

Taking into account the revealed values of macronutrients optimal concentrations and revealed the heavy metals lowest content in the leaves, we assume that Ash-leaved maple *Acer negundo* and Black locust *Robinia pseudoacacia* (compared to the Silver Birch *Betula pendula*) are more resistant to the geochemical conditions of devastated lands. Therefore, species of trees can be recommended for the creation of artificial tree plantations on devastated lands.

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Geographical analysis of ecology-dependent diseases of Kryvyi Rih population in order to provide a sustainable development of the industrial regions

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Abstract. The geographical, ecological and territorial peculiarities of the dynamics and the appearance's reasons of the population's sick rate in dependence on the environment's state of Kryvyi Rih town with the aim of the stable development's provision of the industrial regions. The influence of the contamination's sources on the health state of the Kryvyi Rih population is cleared up and the space-time peculiarities of the sick rate's display are established: the influence of the environmental risks' factors on the population's sick rate and the display of the diseases' separate groups are defined, estimated and mapped, the spreading's indicators of the ecologically dependent pathology from the distance to the stationary sources of pollution and from the factors of the environmental risks are revealed. The statistical base is created and the factors' analysis of the environmental risks, the sick rate, the main demographical indicators of Kryvyi Rih population for the period of 2004 – 2019 is made and it's determined that the sick rate and the mortality, caused by it, play the essential role in the development of the demographical situation of Kryvyi Rih town.

1 Introduction

The peculiarities of the geographical research of the problem of the population's sick rate and its dependence on the display of the environmental risk in the limits of the definite territories are examined in the article. This problem is the geographical – spatial one, because the space-time run of the different types of diseases has the complex character, therefore it's investigated with the help of the geographical scientific methods. The geographical approaches permit also to reveal more efficiently (in comparison with the other sciences) the space-time independence between the appearance of the diseases and the specificity of the municipal environment. In particular, the process of spreading of the ecologically-dependent sick rate in the geographical space is described best of all by the model, according to which the ecologically-dependent diseases are spread from the centers of the environment's contamination, losing its activity from the center to the outlying area.

In contrast to the traditional medical-geographic zoning, the necessity to conduct the ecological-geo-pathogenesis zoning of the territories, on which the definite types of the population's diseases are developed, is proved. For example, the geo-spatial run of the population's sick rate in the industrial regions (Kryvyi Rih) and the separation of the regions with the different level of the environmental risk present the additional proofs, concerning the dependence of the internal-municipal spatial specificity of all the geographical processes and phenomena on the unique configuration and the specific geographical position of the town.

The problems of the population's sick rate interest the geographers for a long time. Such an interest is not accidental, because the geographic or the spatial specificity of these problems has always been so bright that it didn't remain any doubts, concerning the subject field of science, which has to solve them. However, if, except the medics [1, 2, 3], the representatives of the natural-geographic sciences were engaged in these problems, in particular, the bio-geographers [4, 5] not so long ago, then, the geographical [6-8] and the ecological approaches [9] become more and more actual lately in many publications. Due to this, the problems' studying process of the geographical peculiarities of the ecologically-dependent diseases' formation at the higher educational establishments gains the special actuality.

2 Literature review

Considering it necessary to research the theoretical-methodic turns of the ecologically-dependent diseases' problem, the authors made the analysis of the conducted theoretical and practical researches of the population's sick rate's problem and indicated the methodological landmarks strictly for the geographic sciences:

- the problem of the population's sick rate is almost not determined without the getting used to the space-time continuum. The first scientific researches in this direction didn't deal without the geographic maps [10];
- the spreading of the sick rates in the form of the epidemics, epizootics or epiphytes expresses the aspiration for the model "center-outlying area" [11],

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generally known in the geographic sciences, and still further – the theory of the innovations' diffusion of T. Hegerstrand [12, 13];
- the majority of the medical-geographic researches is connected with the natural centers of the diseases' appearance and uses the landscape-scientific approaches [14];
- the medical-geographic researches of the ecologically-dependent diseases (changes of the arterial pressure, the disease of the respiratory organs' systems, the urinary-sexual system and others) are more frequently connected with the anthropologic-genetic changes of the environment (the contamination of the atmospheric air by dust and chemical combinations, the radio-active contamination, the influence of the electromagnetic artificial fields and noise on health) [15, 16];
- the joint task of the Medicine and Geography is the search of the ways of the optimal interaction between the individual, economy and environment, both as the natural one and as the one, created by him (her) [17], the same tasks are solved by the conception of the stable development [18, 19];
- the single conception of the non-zero or the accepted risk dominates at the present time, because the risk's level in any system cannot be equal to zero and it changes in the limits of the probability from 0 to 1, where 0 is the probability of the absolute inertness (the event does not happen in any case), 1 is the risk is realized (the event has happened) [20];
- there is no distinct definition of the notions social, ecological, medical risk, the risk of the human diseases' appearance. There is the notion "environmental risk" [21] in the foreign publications as the risk for the human health in the result of changes of the environment's quality; there is the notion "risk factors in health and disease" [22], in which the ecological factors, influencing the health state of the individual and the appearance of the diseases, act as the separate component. The authors will come out of the most widely-used notion "environmental risk" in the presented research, which acts as the inter-discipline and complex notion and permits to make the research of the ecologically-dependent diseases of the Kryvyi Rih population and to elaborate the measures on the provision and control of the risks' high levels.

One general conclusion flows logically out of the points, mentioned above – the population's sick rate appears in the background of the complex interaction of the person with the environment's elements, where he (she) lives or works. And if the scientists were mostly interested in the natural components, being the objects of the investigation of the natural-geographic sciences [23-25], of this environment till the middle of XX century, then, the main priorities of the latest decades are presented mainly to the social and techno-genetic environment, which are already the objects of the geographic sciences [26, 27]. At this, the ecology joined the subject sphere of the medical-geographical problems which has more right for the research of the interrelations of the organism and the environment. However, such its direction as the ecology of an individual is recognized among the medics-geographers as being "their own" [28, 29]. Afterwards, you may state that the problem of the population's sick rate is also ecological.

The geographical peculiarities of the territories and their influence on the display of the population's ecologically-dependent diseases play the significant role from the view point of the stable development's conception. According to the results of the author's researches, the modern social-economic and medical-geographical specificity of Kryvbas is much determined by the original territory's stretching form of Kryvyi Rih town. But such form is the direct result of the spatial localization of the ore body, at the processing of which the settlement boundary was formed. Afterwards, the geological structure of Kryvyi Rih town forms that fundament, on which the further social-geographic, ecologically-medical processes are developing [30].

Unfortunately, the modern geographic researches are conducted mainly in the narrow scientific spheres and they don't have the features of the complex and inter-discipline researches [28], but as far as the works, devoted to the "joint" directions, in particular, between the physical and the social geography, are concerned, – they are the single ones [22]. To our mind, the very such "joint" is formed during the last decade in the scientific approaches to the problem's study of the population's sick rate. The works of the geologists, the bio-geographers, the landscape scientists, the cartographers [29-32] appear still more and more frequently in the background of the great number of the investigations, conducted by the medics and presented mainly in the periodical publication "Environment and Health". The interest of the geographers to this problem grows more and more [8]. The legitimateness of such approaches' use is confirmed in the classical works on the diffusion of the innovations, where the spatial widening of the diseases is connected with the definite periods (stages) of the geographic space's focusing [13].

The foreign researchers also pay an attention to the problem's inter-discipline character of the appearance of the ecologically-dependent diseases and the environmental risk, among their number they separate such risk's factors: the behavioral, physiological, demographic, ecological, genetic ones [22], speak on the necessity to unite the efforts of geography, psychology, sociology, law, economics, the public policy in the researches of the social risks [33]. Thus, in our opinion, the very such multi-factuality and the inter-discipline should become the leading characteristic feature, positing the problem of the geographic research of the population's ecologically-caused diseases.

It's difficult to research such a complex scientific problem from the position of one science, which would take into account, if possibly, all the components of the system "nature-population-economy": climate, the geo-chemical background, the vegetable and animal world, the danger's degree of natural disasters, the level of the economic development, the social-political order [34]. Correspondingly, the necessity appears to use the ways, methods and modes of the tasks' solvation in physical geography, geology, geo-physics and other natural sciences. Each of them, in its turn, absorbs the

knowledge's elements of the overlapping sciences, due to which gains the new results, necessary to reveal the regularities of the interaction of the nature and the society.

Such a complex approach to the problem's study of the people's sick rate started to develop actively on the land of the USA, beginning from 1980, when the ecological strategy of the state included the state management of the nature-use and the market mechanisms of its regulation. The very conception of the environmental risk has become the basis of the state ecological policy of the USA, according to the definition of the National Academy of Sciences of the USA, the estimation of the risk – is the use of the available scientific information and the scientifically-grounded forecasts for the arrangement of the influence's security of the harmful conditions and materials on human health [35]. At the same time, in the middle of the 80-s of XX century, the researches of the natural risks started to be held under the leadership of the professor S. M. Myahkov at the geographic faculty of MSU (Russia), he founded the bases of the new scientific direction – "Geography of Natural Dangers and Risk" [36].

At this, the "way out" to the practical solvation of the problem in the research of the notion "environmental risk" is considered by the authors to become still more important. The risk's notion in the presented case is complex and it includes: the estimation of the ecological intention's sharpness of the definite geographical region, the level of the population's sick rate, dependence of the incidence of the population on the environmental situation and others.

It's hard to speak of the problem's research of the ecologically-dependent diseases without their relation to their spatial display and the determination of the space-time causes by the factors of the environment. The formation of the complex component's and the medical-geographical maps effects sufficiently the formation of the theoretical-methodological bases and the methodic ways in the medical-geographic researches, increases their meaning in the management's affair of the development and the territorial organization of health protection [37, 38].

The application's possibilities of GIS technologies at mapping of the ecologically-dependent diseases and the separation of the medical-geographical regions are important, their reflection on the map – is the result of the medical-geographic zoning, which reflects the objectively existing territorial dynamic systems, being similar enough on conditions of the social health formation [39].

The special relations in the middle of the medical-geographical regions are formed between the inhabited localities and the landscapes, surrounding them: the definite resources are withdrawn out of the nature, but the different wastes, which can be involved into the natural cycles of the circulation and create the unfavorable conditions for the population's health, enter the natural complexes.

The number and the sizes of the inhabited localities increase with the development of the territory. Sometimes the run of the processes acquires the reverse character in so-called the depressive regions – the number of the population becomes less; the agricultural fields are overgrown and others. The analysis of all the changes, happening in the structure of the medical-geographical regions, permits to reveal the main regularities of their development and to create the medical-geographic forecasts on this basis [39].

The researches of the ecological problems have become more intensive for the last years, the medical geography began to develop qualitatively new approaches and methods for studying the incidence of the population. Therefore, the thought begins to widen among the geographers that the sick rate of the population may be considered to be the most sensitive indicator, characterizing the environment's influence on the person and vice versa [40, 41].

Properly, paying the attention to these new approaches, the authors formed the idea of the ecologically-dependent diseases [42], being confirmed in the other modern works too [16, 21, 43]. Thus, according to the opinion of O. P. Gavrylenko [40], there are such indicators among the negative indicators of ill-health, the spreading of which depends, to a certain extent, on the state of the environment. These diseases are called the ecologically-dependent [40]. The environment can also have the characteristic features, being strictly not pathogenic for the person, but during the interaction with them the potential danger for the person to have the disease grows. We call such an effect as being multiplicative, caused by the phenomenon of synergism, in our works [20, 42]. This is the thing that causes the actuality of our research.

Basing on the analysis of the previously conducted researches in the sphere of the ecologically-caused diseases and the influence of the ecological factors on their appearance, the conducted researches of different types of risks, the grounded theoretical-methodological bases of the indicated problem, the authors investigated the geographical and ecological peculiarities of the dynamics and the reasons of appearance of the population's sick rate in dependence of the environment's state of Kryvyi Rih town. The analysis of the sick rate for the separate diseases on the territory of Kryvyi Rih, as the industrial town, is made with the help of the specialized data base in the environment GIS MapInfo Professional. The territorial peculiarities of the population's sick rate of the industrial region are researched in the work, the classification of the Kryvyi Rih regions, according to the population's sick rate, is made, the ecological-geo-pathogenic zoning of the Kryvyi Rih territories is grounded and made on the basis of the investigation of the internal-regional peculiarities of the population's sick rate. The research results are introduced by the authors into the training process of the Geographic faculty's students and are included into the lecture-practical studies on the disciplines "Geo-Ecology", "Bases of Geo-Ecology", "Ecology and Ecological Tourism".

The influence of the contamination's sources on the population's health state of Kryvyi Rih town is cleared up and the space-time peculiarities of the sick rate's

display are established (the influence of the environmental risks' factors on the population's sick rate is defined, estimated and mapped). The research is conducted at the Department of Physical Geography, Regional Ethnography and Tourism on the basis of the Kryvyi Rih State Pedagogical University by the collection and the statistical analysis of the factors' data of the environmental risks, the sick rate, the indicators of the birth-rate, mortality and natural increase of the Kryvyi Rih population in the period of 2004–2019. The factors of the environmental risks are estimated, the stable dependence of the ecologically-caused diseases on the pollution of the atmospheric air, the surface waters, the grounds is revealed, the statistical analysis of the population's sick rate is made and the ecologically-dependent diseases are mapped, the dependence's indicators of the ecologically- dependent pathology's spreading from the distant area to the stationary sources of contamination and on the factors of the environmental risks are revealed.

It's determined, that the very complex geographic researches of the population's sick rate acquire more and more importance on conditions of the stable development's provision of the industrial cities, because their display and results have the double character: from one side, they are caused by the ecological situation of the region and are the display's result of the ecological factors of different genesis (the pollution of the atmosphere, the surface waters, grounds and others), from the other side, – they are the expression of the separate type of the environmental risks.

The geographical approach to the state's study of the population's sick rate for the ecologically-caused diseases of the industrial region, in dependence on the complex of the landscape, social-economic and ecological characteristic features of the separate territories, is improved.

3 Methods

The research is conducted with the use of the general-scientific ways and methods: the statistical-mathematical (for the estimation of the quantitative parameters of the population's sick rate with the ecologically-dependent diseases, the estimation of the ecological situation of Kryvyi Rih town and the contaminations from the stationary and movable sources, the estimation of the environmental risks' factors); the mathematical (for the calculation of the spreading's dependence indicators of the ecologically-dependent pathology from the distant area to the stationary sources of pollution); the system-structural and the system-functional analysis (the research of the complex connections in the system "nature-population-economy", appearing in the development's process of the ecologically-dependent diseases in the industrial regions). The special ways and methods are used: the comparative-geographical analysis (the study of the territorial distinctions of spreading of the ecologically-dependent diseases, the dependence's determination of the ecologically-dependent diseases on the factors of the environmental risks); the historical-geographical analysis (the research of the space-time regularities of the display of the environmental risks and the ecologically-dependent diseases, the dynamics of the ecological situation, the sick rate, the birth-rate, mortality and the natural increase); the cartographical one (the realization of the territorial differentiation and the spatial analysis of the sick rate's appearance and spreading and the determination of the sick rate's dependence on the display of the environmental risks' factors in the limits of the definite territories, the realization of the medical-geographic zoning); the probability one (the methods of the factors' estimation of the environmental risks on the basis of the probability of the landscape's refusal to fulfill the set functions), elaborated by M. D. Grodzynsky [44, 45]: 1 – the estimation's methods of indicators, according to the frequency of the events (refusals, restorations, the transition between the states' spheres), 2 – the methods of estimation, according to the function of the incidental values' distribution (time of the refusal's appearance or the restoration of the landscape), 3 – methods of estimation, according to the variation of the indicators in the limits of the set range.

4 Results

The territory of Kryvyi Rih belongs to the steppe landscape's zone. It's determined by the research on the basis of the functional analysis of the town that the industrial zone consists mainly of over 100 enterprises of the mining-extractive (mines, carriers, the area is 33 sq.km), processing and metallurgical branches (5 mining-dressing combines, the metallurgical combine "ArcelorMittal Kryvyi Rih", a series of the machine-building and processing plants); the residential area – is represented by the low-building's and tall-building's residential areas, the cottage settlements; the agricultural one – by the arable lands of different specialization, the pasture-grounds and the garden landscapes; the water farming – by the rivers, storage reservoirs, the irrigating and arterial canals, lakes; the travelling-transport one – by the railways and automobile roads of different categories, the garage and station complexes; the environment-creating one – by the forestry complexes, parks, squares and the objects of the natural-protected land fund (the landscape areas of the general-state meaning – the "Ingulets steppe" and the "Balka Pivnichna Chervona"); the zone of the marching complexes is represented by the various destructive landscapes and the waste grounds.

The industrial, residential and agricultural landscapes dominate in the territorial structure of the town. The difficult interaction of nature and economy leads to the formation of the different anthropogenic and anthropogenically modified landscapes, but putting of the anthropogenic processes over the natural ones leads to the formation of the ecological situations and creates the pre-conditions for the active display of various types of the environmental risk, the estimation's results of which are presented lower.

The risk's estimation of the atmospheric air pollution showed that nearly 90 % landscapes of Kryvyi Rih are characterized by the levels of probability of occurrence 0,7–1, including the residential, environment-creating, water farming zones and the suburban complexes; 10 % – by the probability level of 0,2–0,7. The hydro-geological risks have the very high probability of occurrence (it's displayed in all the water landscapes of the town and was equal to 0,7–1). The probabilities among the hydro-geological risks were estimated in such a way: the indicator of the contamination of the underground waters varies in the limits of 0,2–1, however, 85 % of the territory are estimated by the high probability (0,4–0,7); nearly 6 % – by the very high one (0,7–1); 9 % – are coincided with the exploitation of the deposit – not estimated; the probability of the flooding varies from 0 to 1 and displayed only on 30 % of the territory, occupied by the different hydro technical structures; the risk of the appearance of floating sands and change of big rivers and silting of rivers is presented locally (they are estimated qualitatively as they were spread on the very limited territory of the region). The geological-geo-morphological risks are estimated, according to the four types: the risk of the gravitational processes is represented by the landslides (0,03–0,18) and crumbles (it's revealed on the sides of dumps and carriers, the probability – 1); the risk probability of the formation of fissures and cracks of the land surface above the mine excavations equals 0,02–0,75, but the risk probability of crashes – 0,013–0,25.

The risk of activation of the karst-suffosium processes is estimated by the average and not high meanings of the probabilities (0,2–0,5), it affects the functioning of some types of the landscapes – the residential, agricultural and park ones. The risk of the activation of the tectonic processes is important (0,5–0,75), according to the possible results of its display.

The ground risks are estimated by 4 types: the risk of the grounds' contamination by the chemical substances has the extreme and very high probability (0,7–1) per 50 % of the town area; the risk of the grounds' water logging – not high, but for the separate kinds of the landscapes (especially for the suffosium and the water-dividing valleys, raving and sloping ones) – essential; the risk of the grounds' salting is lighted up by the not high levels of the probability and has the territorial connection with the risks of the water logging and flooding; the risk of the acidity level's change of the grounds is developed in the same types of the landscapes as the two previous ones and has mainly the low levels of the probability's display, except the landscapes of the suffosium valleys [20].

The risk of display of the exotic-genetic geological processes is estimated for 30–45 % of the landscapes' types as the high one (used intensively by the person).

The integral indicator's estimation of the environmental risk probability showed that it is formed on the territory of Kryvyi Rih by 17 types of the risks, being estimated above, but not all of them have the urgent importance in the creation of this indicator's high probability, therefore the analysis was made on the basis of the selection of those types of the landscapes, where the equal probabilities of the separate types of risk were above 0,7. It's stated that the number of risks with the high level of probability ($\geq 0,7$), those ones that urgently cause the high integral indicator, lie in the limits 1–5. The map is made, according to the results of the conducted estimation and on the basis of the component analysis of the risk. The analysis showed that nearly 65 % of the territory experienced the one- and the two-components risk, the significant role here was played by the risk of pollution of the atmospheric air, the surface and the underground waters, the rest one – 35% – experienced the risk, according to the 3, 4, and 5 types of the environmental risk. All the residential tall buildings' and some low buildings', the industrial and destructive, some agricultural and the environment-creating types of the landscapes have the high level of the multi-components' environmental risk. 11 electronic maps of the environmental risks were made for Kryvyi Rih, according to the estimation's results, with the help of the GIS-technologies and Corel draw.

It's determined that the biggest influence on the appearance of the ecologically-dependent diseases is made mainly by the pollution of the atmospheric air, the surface and underground waters, the contamination of the grounds; the special role is played by the probability of the untimely death of the population, due to the various socio-techno-genetic factors, but you shouldn't ignore such a fact that all the complex of the investigated factors of the environmental risk affect the population's state of health and sick rate, because they are in the whole forming the environment's quality of human life and are closely connected with each other.

The authors understand the environmental risk as the probability of the disease's appearance of the person, living or working in the limits of the definite landscapes. The estimation of the environmental risks is made by the authors on the basis of the comparative research of 17 types of risks (the environmental risks, described above) and the indicators of Kryvyi Rih population's sick rate for the period of 2004–2019, and also on the basis of the statistical models' construction of spatial distribution of the effects of environmental pollution on the population's sick rate, dealing with the ecologically-dependent diseases.

The gained data of the environmental risks' estimation testify that the highest indicators of the general sick rate of the population are characteristic for such regions of the town as the Pokrovsky, Saksagansky, the Central-Municipal ones, on the territory of which nearly 50 industrial enterprises are situated, they are mainly the acting mines, carriers and the dumps of the mining-ore-dressing combines and the combines themselves, the full-cycle metallurgical combine "ArcelorMittal Kryvyi Rih". The comparison of the data of the population's general sick rate with the maps of the risk of the town's atmospheric air pollution shows that the territory of the Saksagansky and the Central-Municipal regions coincides with the territory of the mostly polluted air. The lowest indicators of the population's general sick rate are characteristic for the Ternivsky and Inguletsky regions (these are the most northern and the most southern regions of the town), and

if the air pollution's indicators are not high in the Ternivsky region (1–5 of LAC, -the Limiting Admissible Concentration), then, the territory of the Inguletsky region is characterized by the high enough indicators of the pollution (5–15 of LAC). Such situation is explained by the fact that the data of the population's sick rate are collected at the separate remedial-preventive establishments, besides, the balance-wheel migrations of the population also play their roles in the middle of the town and the individual indicators of health (the influence of the genetic, social, moral and other factors).

The analysis of the population's sick rate of Kryvyi Rih for the researching period, according to the groups of diseases, shows that the greatest number of the sick rates of both among the adult population and the children's one is referred to the group of the blood–circulation diseases (point 8 on the graph: Fig. 1, 2) and the diseases of the respiratory organs (point 10 on the graph: Fig. 1, 2), the urinary-sexual system's diseases play a bit less role (point 15 on the graph: Fig. 1, 2) and other diseases (Fig. 1, 2)

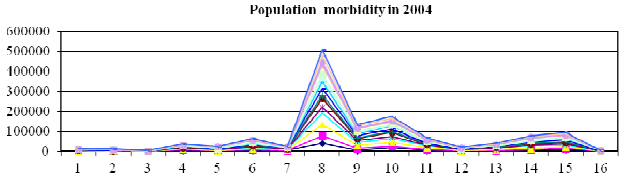

Fig. 1. The sick rate of Kryvyi Rih population for 2004.

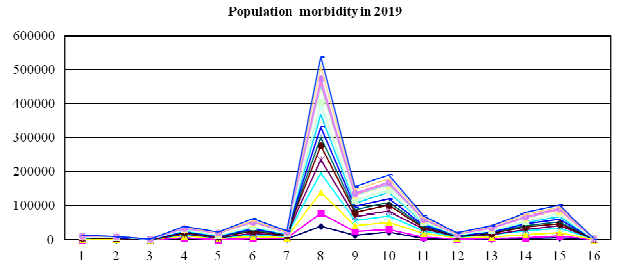

Fig. 2. The sick rate of Kryvyi Rih population for 2019.

The conventional symbols: 1 – some infectious and parasitical diseases, 2 – neoplasms, 3 – diseases of blood, the blood-creating organs, 4 – diseases of endocrine systems, 5 – diseases of nervous system, 6 – eye diseases, 7 – ear diseases, 8 – diseases of blood circulation system, 9 – heart diseases, 10 – diseases of respiratory organs, 11 – diseases of digestion organs, 12 – liver diseases, 13 – skin diseases, 14 – diseases of osseous and muscular system, 15 – diseases of urinary and sexual system, 16 –diseases of milk gland. The total number of diseases at the hospitals is indicated on the graph by the lines.

The research of the spatial distribution's influence of the contamination's sources on the population's sick rate and the gained data of the environmental risk's estimation was conducted, according to the methods of the statistical modelling (the regressive analysis) and with the help of GIS MapInfo Professional. A series of maps of the population's sick rate of Kryvyi Rih town, dealing with the different groups of diseases, was constructed by the authors on the basis of the conducted analysis; the maps of the sick rates with the system's diseases of the blood circulation and the respiratory organs are presented on the figures 3, 4. The constructed maps and the estimated environmental risks visualize and confirm the dependence between the contamination and the sick rate of the population, characterize the sick rate of the population, dealing with the separate diseases.

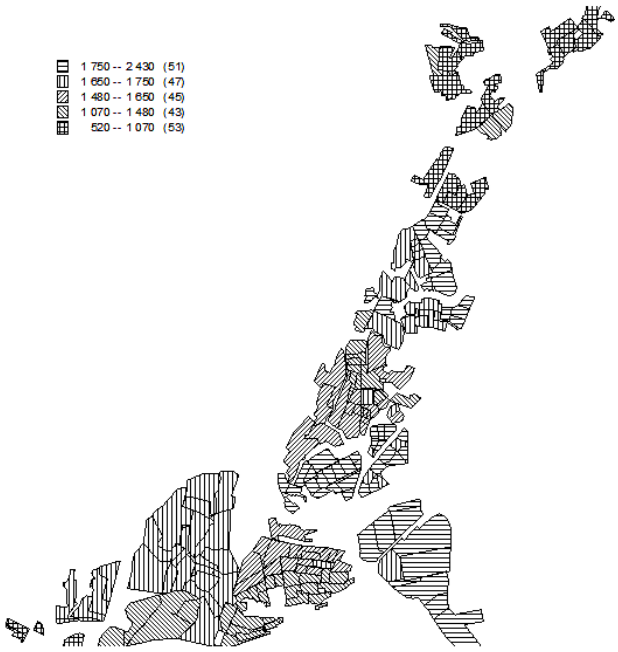

Fig 3. Circulatory system's morbidity data 2019.

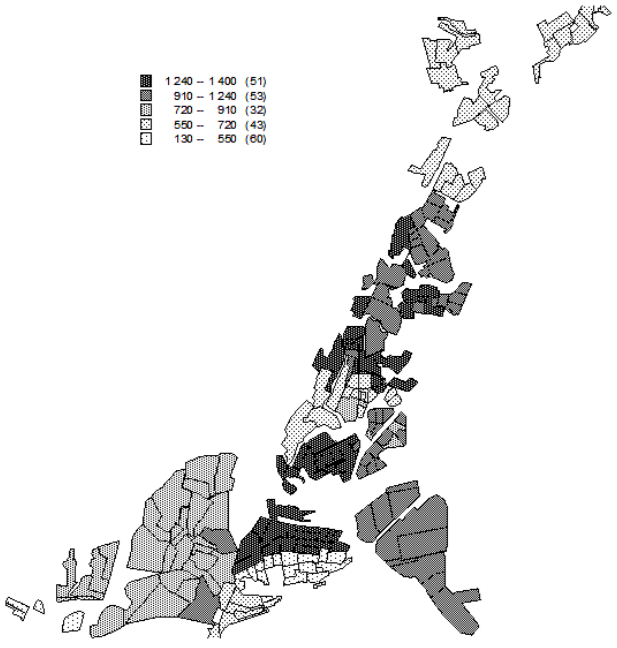

Fig 4. Respiratory system's morbidity data 2019.

In order to construct the regressive models, the authors fulfilled the non-linear analysis for the main groups of the ecologically-dependent diseases for the period of 2004–2019. It's cleared up, that the biggest determination from the quality of the atmospheric air is observed for the diseases of the blood circulation system (the coefficient of the determination is 0,43–0,49), the

diseases of the respiratory organs (the coefficient of the determination is 0,3–0,5).

Some graphics of the regressive disease's dependence of the blood circulation system and the respiratory organs on the distance to stationary sources of pollution in 2004, 2019 are presented lower (Fig. 5, 6, 7, 8).

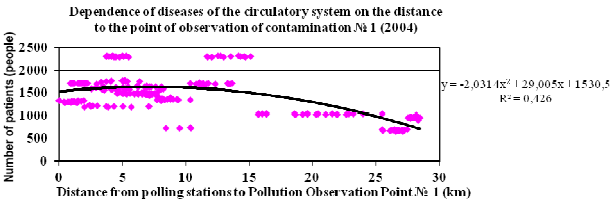

Fig. 5. Regressive model of blood-circulation's disease dependence on distance to stationary sources of pollution (2004).

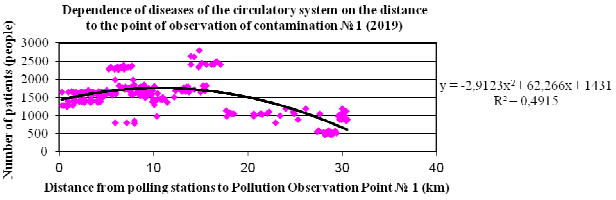

Fig. 6. Regressive model of blood-circulation's disease dependence on distance to stationary sources of pollution (2019).

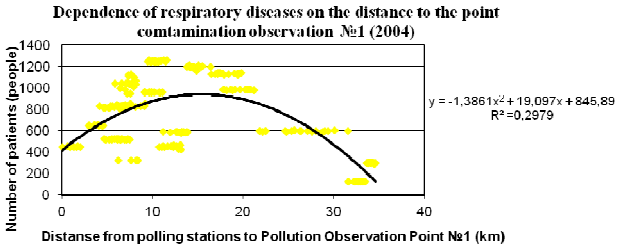

Fig. 7. Regressive model of respiratory organs' disease dependence on distance to stationary sources of pollution (2004).

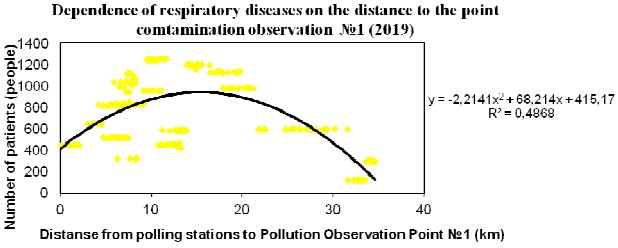

Fig. 8. Regressive model of respiratory organs' disease dependence on distance to stationary sources of pollution (2019).

The analysis of the constructed regressive models (Fig. 5-8) proves that the dependence of the sick rate with the definite groups of diseases on the ecological factors, in particular, the state of the atmosphere, is important. In most cases it is described exactly enough by the polynomial of the second degree with the meaningful coefficients of the determination. The regressive models, presented above, represent the dependence of the population's sick rate on the state of the air basin in the generalized form. The conditional dependence's stability of the definite diseases on the environment's conditions is also confirmed by the statistical analysis on the construction's basis of the model of the spatial distribution of the contamination's influence on the population's sick rate.

Taking into account the results of the investigations and the results of the expert estimations [46, 47], the grouping of the diseases, according to the degree of the different factors' influence on the process of their appearance, was made and the stable interconnection and the dependence of the disease's display on the environment's state of human life is determined (Table 1).

Table 1. Distribution of separate components into creation of ecologically-dependent diseases.

	Diseases	Contribution of separate components			
		ecological	social	genotype	industrial
1	Some infectious and parasitical diseases	++	+++	++	+
2	Neoplasms	+++	–	++	++
3	Diseases of blood, blood-creating organs	++	+	+++	+
4	Diseases of endocrine system	+++	++	++	+
5	Diseases of nervous system	–	++	+	+
6	Diseases of eye and adventive system	++	+	++	++
7	Diseases of ear and comforter-type appendix	–	+	+	++
8	Diseases of blood circulation system	++	+	++	++
9	Heart diseases	++	++	++	+++
10	Diseases of respiratory organs	+++	++	++	+++
11	Diseases of digestion organs	+++	+++	++	+++
12	Liver diseases	++	++	++	+
13	Diseases of skin and hypodermic cellulose	+++	++	+	++
14	Diseases of osseo-us-muscular system	+++	++	++	++
15	Diseases of urinary-sexual system	+++	+	+	++
16	diseases of milk Gland	+++	++	+	+

The peculiarities of the environmental risks' display, the character of the population's sick rate distribution, the display of the most number of the diseases of the separate groups (blood circulation system and respiratory organs), determined by the authors, may influence the indicators of the birth-rate, mortality and the natural increase of population.

The distribution of the dead people's quantity for the separate reasons of death throughout Kryvyi Rih town

(Fig. 9) shows that the first place is occupied by the diseases of the blood circulation system (67 %), the second one – the oncological diseases (12 %), the third one – the diseases of the respiratory organs (3 %) and other diseases.

The number of Kryvyi Rih population was reducing during the research period (2004–2019). It was caused by the small number of the new-born children, not exceeding the number of the dead people, and the negative balance of the migration from 2007. The population is getting old, due to the growth of the average duration of life and the small quantity of the new-born children. The part of the young people reduces, but the part of the elderly people grows. From 2004 to 2019, the coefficients of the birth-rate (the average number of children, born by the average-statistical woman during the life) grew constantly: from the indicator of 0,97 of a child for a woman in 2004 till 1,32 of a child for a woman in 2019, the summary coefficient of the birth-rate doesn't achieve the level of the natural replacement, being equal to 2,1 – it means that the number of the town population will be less, if the migration balance is left negative.

The number of the population reduced, first of all, due to the constantly high coefficient of mortality among the elderly people. Besides, the small quantity of the new-born children and the flow of the population back didn't give any opportunity to compensate the indicator of mortality. The migration's flow of the population back, which started in 2007, was caused by the optimization of the personnel's number at the powerful enterprises of the town, especially by the introduction of the programs, concerning the personnel's dismissal, according to their own wish, from the PJSS "ArcelorMittal Kryvyi Rih". At the same time, the tendency, concerning the reduction of the migration's upsurge of the population, was observed.

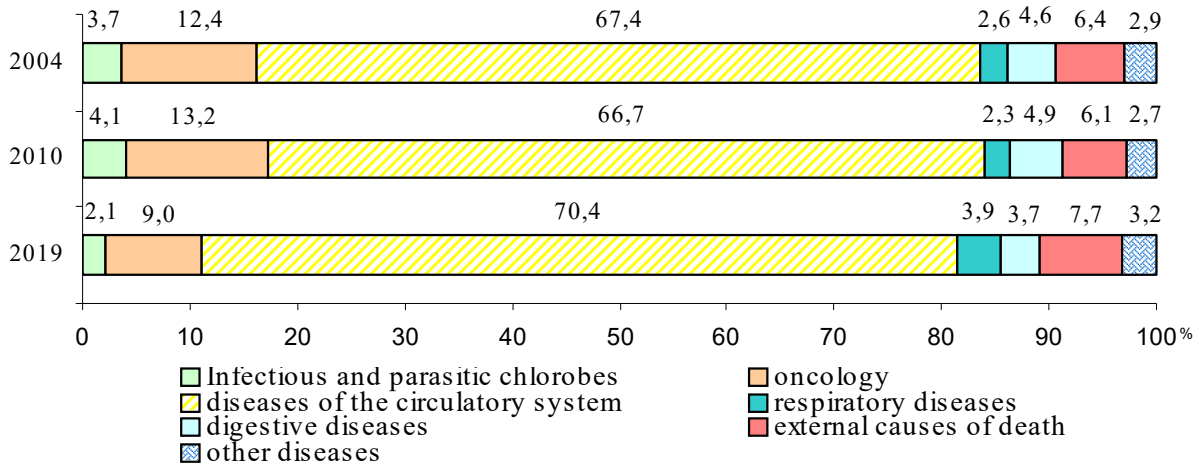

Fig. 9. Distribution of dead people's quantity in time cuts for separate reasons of death.

5 Conclusions

The scientific results of the research have the special methodical and practical value for the realization of the similar scientific investigations in the other industrial regions.

The conducted analysis and estimations are the methodic and practical basis for the realization of the Kryvyi Rih strategic development, particularly, in the parts of the territorial planning of the town, the organization of health protection, the ecological monitoring of the territory, the statistical data base and others. The cartographical, ecological, medical data, being gained in the research, are used by the statistical department of Kryvyi Rih town, the department of health protection of the municipal executive committee of Kryvyi Rih, the ecological department, the ecological inspection, the department of architecture and planning and also the Institute of the town's development.

The complex of the events [20], being oriented at the minimization of the environmental risks, being realized via the landscape- and territorial-planning, the environment-creating events, are elaborated. The research results are taken into account in the project of creation of the Kryvbas ecological net, the organization of the sanitary-protective and water-safeguarding zones of the rivers and water reservoirs, the buffer zones of the nature-protection objects, the suburban zones of the town.

The results and the regularities of the formation of the ecologically-dependent diseases, the medical-geographic zoning of Kryvyi Rih territory may serve as the ecological criterion of the environment's quality of human life and be correspondingly used by the local population for the selection of the place of the residential premises' location in the limits of Kryvyi Rih town. Besides, the knowledge of the ecological situation of the definite region may be one of the criteria of the formation of the cost and price of the residential premises (rent or purchase) and the basis for the creation of the so-called "ecological rent".

The expressed positions of the article are used in the scientific and training processes at teaching of the disciplines of the ecological, geographical and cartographical direction at the Kryvyi Rih State Pedagogical University.

Thus, the research, conducted by the authors, is directed at the provision of the stable development of Kryvyi Rih, in which there are:
1) the rational and complex use of natural conditions and resources of the Kryvyi Rih basin of iron ores;
2) the healthy qualified environment of population life;
3) the influence's minimization on natural components (requires the diligent research in the perspective).

The geographic research of the ecologically-dependent diseases of Kryvyi Rih population showed that the display and the consequences of such sick rates have the double character: from one side, they are caused by the ecological situation of the region and are the display's result of the ecological factors of different genesis (the pollution of the atmosphere, the surface waters, grounds and others), from the other side, they are the expression of the environmental risks of separate type and in such case it's the probability of the disease's appearance for the person, living in the limits of the definite town.

The conducted analytical, statistical, graphical and the cartographical researches confirmed the position on the fact that the original environment of the population life is being formed in Kryvyi Rih town (with its specific configuration, socio-economic peculiarities, economic specialization in the spheres of the extractive and processing industry). The display's peculiarities of the separate types of the environmental risks, which appeared to be high and extremely high in the limits of the researched town, are determined by the authors. It's cleared up that all the residential tall buildings and some low buildings, the industrial and destructive, some agricultural and environment-creating types of the landscapes have the high level of the multi-component's environmental risk, – thus, the town territory is characterized by the extremely low environment's quality of human life.

The formation's peculiarities of the ecologically-dependent diseases and their space-time dependences are determined. Such comparisons of the space-time regularities of the display of the environmental risks and indicators of the population's sick rate showed that the maximal risk to get the disease is characteristic for the people, who live in the limits of the terrace tall landscapes (0,90), and *a* little bit less – in the limits of the flood-landed, low, the terrace low, the erosive-ravine and powerful tall and low buildings, near the water-dividing valley tall buildings' landscapes (0,71–0,78), the lowest probability of risk is defined for the water-dividing valley low buildings' types of the landscapes (0,54). The analysis of the population's sick rate, according to the group of diseases, showed that the greatest number of the population's sick rate both among the adult population and among the children's population is referred to the group of the diseases of the blood circulation system, the respiratory organs, the other diseases play a bit less role. These data are confirmed by the constructed statistical regressive models – the dependence of the sick rate with the definite groups of diseases on the ecological factors is revealed, in particular, the atmosphere state, the regressive dependence of the sick rate of the blood circulation system and the respiratory organs on the distance to the stationary sources of pollution.

It's stated on the basis of the analysis of the main demographic indicators and the indicators of the population's sick rate of Kryvyi Rih that the sick rate and the mortality, caused by it, play the essential role in the development of the demographic situation.

Thus, the authors confirmed the supposition on the fact that the display of the ecologically-dependent diseases in the industrial towns is constantly connected, in the first turn, with the high levels of the pollution's probability of the atmospheric air, the surface and underground waters, grounds; the indicators' dependence of the birth-rate, mortality and the natural increase of the town's population on the high level of the probability of the environmental risk's display is cleared up.

It's determined that the very complex geographic researches of the population's sick rate acquire more and more importance on conditions of the stable development's provision of the industrial cities and towns.

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Visual test determination of trace amounts of germanium in the form of an ionic associate of 12-molybdogermanate with astrafloxin

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Abstract. Sorption-colorimetric and naked eye determination of germanium as ion associates of $GeMo_{12}O_{40}^{4-}$ with triphenylmethane dyes is described. The sorption of the ionic associates (IA) of 12-molybdogermanat with astrafloxin (AF) on filter paper was studied. The colored scales for naked eye detection and dependence of chromaticity coordinates from the germanium (IV) concentration were obtained. The methods were applied to the determination of germanium (IV) in coked coal, iron ore, and in waters in the concentration range from $4•10^{-8}$ to $1•10^{-6}$ mol•L^{-1}. The developed test-systems for the determination of Germanium in natural and technological objects were tested in the course of training students of chemistry of Kryvyi Rih State Pedagogical University.

Introduction

Control of the content of germanium is necessary when it is extracted from ores, concentrates, coal, in its production, in cosmetics and medicines, in food. Plants that are capable of absorbing germanium and its compounds from the soil include: ginseng, garlic, camphor, aloe, tomatoes, beans, chickpeas, sunflower seeds, mushrooms and wheat bran. Germanium is also found in milk and in salmon meat. Germanium is an important trace element for humans, capable of accumulation. But its excess in the body or lack leads to the formation of various diseases. Germanium deficiency can be dangerous, since in this case the risk of the onset and development of cancer, as well as osteoporosis, is increased.

Today it is necessary to have reliable, simple and relatively fast methods for its determination. The main methods for the determination of germanium (IV) today: atomic absorption method with electro-thermal atomization of the sample (AAS-ETA) [1, 2], with mandatory preliminary concentration, atomic emission spectroscopy with inductively coupled plasma (AES-ICP) [4], voltampermetric determination of germanium. Highly selective methods of atomic absorption analysis with electrothermal atomization or hydride version have their drawbacks. First of all, matrix elements interfere strongly with the determination, and the separation process only complicates and increases the analysis time. X-ray spectral and neutron activation methods to achieve sensitive, Sn = 10^{-3} μg. But as for Germanium there is the problem of the formation of refractory carbides, introduced impurities from reagents, and other factors that interfere with the determination using physical methods of determination.

A significant part of the existing methods for determining germanium (IV) are spectrophotometric, with mandatory separation procedures. The main methods of separation are distillation or extraction of germanium chloride in a strongly acidic medium in the form of a complex with phenylfluorone or other reagents. But these methods also have their drawbacks - the slow formation of a complex with phenylfluorone.

Therefore, it is relevant to develop highly sensitive, express methods for the determination of low contents of germanium (IV) and the creation of test methods for its semiquantitative determination.

To enhance the analytical signal in modern analysis, began to use the inclusion of chromophore groups with a high molar absorption coefficient in the analytical form. Until this time, triphenylmethane dyes, antipyrine and rhodamine dyes were most widely used (Table 1). The pH range in which these dyes exist in a cationic form is narrow. Recently, polymethine series dyes with a high molar absorption coefficient and a sufficiently wide pH range for the existence of singly charged cations have attracted their attention.

With these dyes, ionic associates (IA) of heteropolyanions (HPA) form solutions or pseudocolloidal solutions that allow the determination of heteroatom elements at a concentration level of 10^{-8}–10^{-7} mol/L [3, 6].

Currently, there are not enough test methods for determining germanium.

This work is devoted to studying the conditions of selective sorption of the ionic associate (IA) of the molybdogermanium heteropolyanion (GPA) with the

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representative of polymethine dyes – astrafloxin (AF) on cellulose paper (Table 1).

Reagents and equipment

All solutions were prepared using bidistilled water and stored in plastic containers. To obtain the IA of the molybdogermanium complex (MGK), the following was used: the initial 0.01 M solution of germanium (IV) was prepared by dissolving the corresponding portion of the GeO_2 grade of os.h. with a solution pH of 11.5; 0.1 M solution Na_2MoO_4 – from the recrystallized $Na_2MoO_4 \times 2H_2O$ grade of the chemical grade product recrystallized from a water-alcohol medium; $1 \cdot 10^{-3}$ M solution of astrafloxine was prepared from the preparation of the analytical grade mark $C_{25}H_{29}N_2Cl$ (Basic Red 12, 1,3,3-trimethyl-2- [3- (1,3,3-trimethyl-2-indolinylidene) propenyl] – 3H-indolium chloride). Solutions of a lower concentration were obtained by diluting the stock solutions. For dynamic sorption on filter paper, a column was used (Fig. 1):

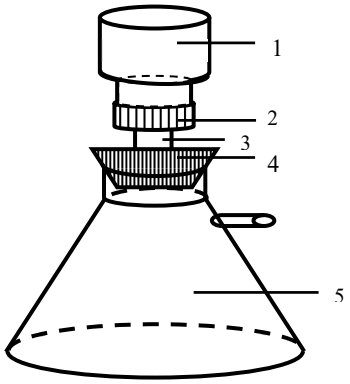

Fig. 1. Column for dynamic sorption on filter paper: 1 – a funnel with thread (2) and a plate for filter paper; 3 – glass connecting tube; 4 – rubber stopper; 5 – flask with a tube for filtering under vacuum.

Table 1. Photometric determination of Germanium in the form of IA with HPA with organic dyes.

Element	Analytical form	Colorant	λ, nm	ε, l·mole^{-1}·cm^{-1}	detection limit, mg/l	Source
Germanium	$GeMo_{12}O_{40}^{4-}$	Crystalline violet	590	$1{,}8 \cdot 10^{-5}$	0,025 – 0,3	[1, 3]
		Malachite green	620	$1{,}6 \cdot 10^{-5}$	0,030 – 0,4	[6, 3]
		Brillian green	620	$1{,}93 \cdot 10^{-5}$	0,025 – 0,35	[1, 3]
		Chrompyrazole	610	$0{,}43 \cdot 10^{-5}$	0,1–1,0	[5, 8]
		Rhodamine 6G	610	$1{,}34 \cdot 10^{-5}$	0,025 – 0,4	[6, 11, 10]

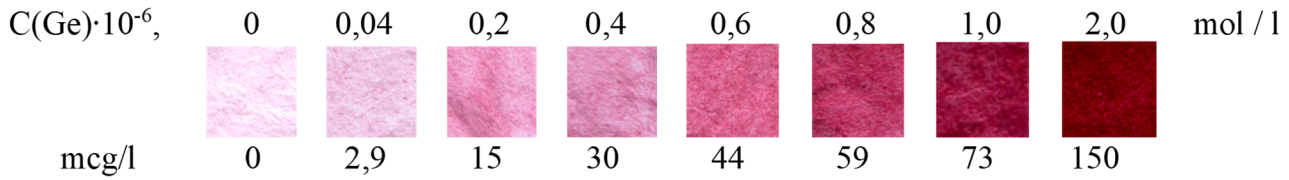

Fig. 2. Scanned test scale for visual test determination of GeO_4^{2-} in the form of IA 12-MGK with astrafloxin on filter paper.

Experiment techniques

Preparation of β- $GeMo_{12}O_{40}^{4-}$ IA with astrafloxin: the necessary volumes of $1 \cdot 10^{-6}$ M Ge (IV) solution were added to 25 ml flasks to obtain concentrations of $0{,}04 \cdot 10^{-6} - 2 \cdot 10^{-6}$ mol/L, 0 each, 6 ml of $1 \cdot 10^{-2}$ mol/L Na_2MoO_4 solution, 0.5 mol/L H_2SO_4 solution to create the required pH (1.5-2.0). The reaction is fast. Then, 2 ml of a 0.6 M solution of tartrate acid were added, after which the molybdogermanic acid solution was re-acidified, 1.5 ml of 5 M H_2SO_4. Then, in small portions, with constant stirring, 1 ml of 10^{-4} mol/L AF was added, and distilled water was brought to the mark.

Obtaining a test scale for the visual test determination of GeO_4^{2-} dynamic sorption was used. The resulting IA solution was passed through filter paper. Accelerated the passage of the solution using a vacuum pump. The resulting sample was removed from the column, dried in air, and then the resulting scale was scanned (Fig. 2).

In the absence of equipment for measuring diffuse reflection, colorimetric analysis is a simple and affordable method that is not inferior in efficiency. Measurement of staining intensity of IA sorbates on paper.

The method of carrying out colorimetric measurements: the scale prepared for the above-mentioned method is scanned against a white background in the color image mode (separation ability 600 × 600 dpi or more) The brightness / contrast ratio is set to 30/0. Using the Paint graphical editor, cut out 170x170 or smaller pixels from the scanned image. For each pixel in the image, R, G, B – color coordinates [2] are calculated and averaged over the entire data array.

Results and discussion

We studied the optimal conditions for the formation of a colored ionic asociate (IA) of a 12-molybdogermanium complex (12-MGC) with polymethine dye cations astrafloxin (AF) in a solution and its sorption on cellulose paper. The formation of the ionic associate AF-MGK was carried out in two stages.

At the first stage, a yellow oxidized molybdogermanium complex was obtained by

acidification of a mixture of solutions that contain GeO_3^{2-} and MoO_4^{2-}.

The second acidification was carried out to prevent the formation of persistent IA Astrafloxin with isopolymolybdate ions. The excess of molybdate ions was masked with hydroxy acids.

The reaction of the formation of IA MGK with astrafloxin occurs instantly. The reaction is selective with a fairly high sensitivity. The selectivity of the formation reaction may be impaired by the formation of colored IAs with large anions, but their solubility is much greater than the solubility of IAs with heteropolyanions. Therefore, there is no interfering effect of such anions: HCO_3^-, SO_4^{2-}, NO_3^-. Table 2 shows data on the effect of a number of ions on the determination of germinate ions.

Table 2. The maximum excess of foreign ions that does not affect the determination of Ge ((IV) in the form of $GeMo_{12}O_{40}^{4-}$ with AF. C(Ge)=4·10^{-7} mol/L.

interfering ion	**Na^+, K^+, Mg^{2+}**	**NO_3^-, Cl^-, AsO_4^{3-}**	**Ni^{2+}, Zn^{2+}, Cu^{2+}**	**Fe^{3+}**	**CO_3^{2-}, PO_4^{3-}**	**SiO_3^{2-}**
molar ratio C_{Ge} : C_X	1:1000	1:500	1:400	1:100	1:50	1:5

The decrease in the interfering effect of silicates in the determination of germanate ions is explained by the fact that the reaction for the formation of MGC proceeds in a more acidic environment. In this pH range, molybdosilicate is not fully formed. In this case, the molybdosilicate complex (MSC) is formed very slowly for 15-20 minutes, and the modibdogermanate complex – quickly, 1-2 minutes.

We have for the first time shown the possibility of a highly sensitive visual test determination of Ge (IV) after selective concentration of IA 12-MGA with polymethine dye AF.

Calibration graphs were obtained for the colorimetric determination of Ge (IV) in the coordinates of the R and B functions (red and blue) – logC (Table 3) or $(255\text{-}G)^2 / 2G = f(C)$ and the possibility of correlation of this dependences with spectrophotometric in coordinates A - $(255\text{-}G)^2 / 2G$.

Table 3. Color coordinates R, G, B obtained after scanning stained samples of filter paper with sorbed IA $GeMo_{12}O_{40}^{4-}$ - AF

C_{Ge}·10^{-6}, mol/L	**R Color**	**G Color**	**B Color**	**lg(C)**
blank test	243	242	241	0
0,04	230	196	186	-7,398
0,2	188	177	127	-6,699
0,4	154	169	99	-6,398
0,6	135	134	68	-6,222
0,8	127	87	39	-6,097
1	113	79	24	-6,00
2	92	44	12	-5,699

The dependence of the R, G, and B color coordinates on the concentration of IA is exponential (Fig. 3.a, Fig. 3.b). R and G color coordinates upon IA $GeMo_{12}O_{40}^{4-}$ - AF sorption change most naturally and in a wider interval. Data were processed using the modified Kubelka-Munk equation (Fig. 4). The equation of the calibration graph in coordinates $(255\text{-}G)^2 / 2G = f(C)$, where G is the value of the color coordinate R, and C is the concentration of Ge (IV) in mol/L, is described by the expression (-4,1±1,5) + (3,16±0,11) · 108 · C Ge (IV), the correlation coefficient is 0.995. The detection limit calculated by the 3Sa / b formula is 4 · 10^{-8} mol/L.

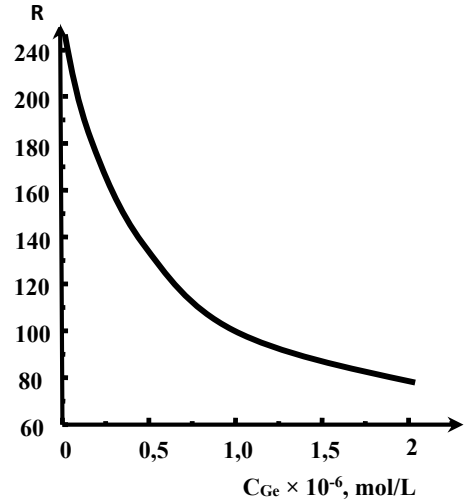

Fig. 3a. Dependence of coordinates R - functions of Ge (IV) concentration after sorption **$GeMo_{12}O_{40}^{4-}$ - AF**

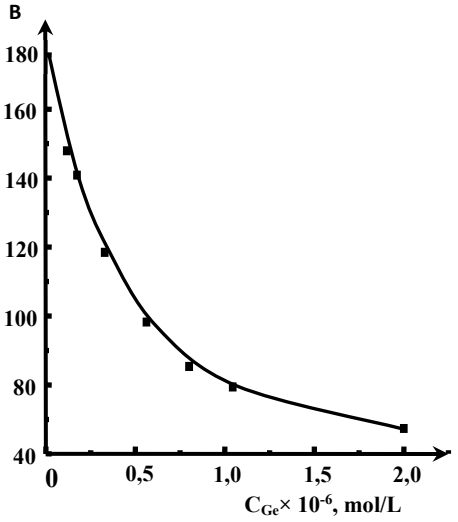

Fig. 3.b. Dependence of coordinates B - functions of Ge (IV) concentration after sorption IA $GeMo_{12}O_{40}^{4-}$ - AF.

Calibration graphs were obtained for the colorimetric determination of Ge (IV) in the coordinates of the R and B functions (red and blue) – logC (Table 3) or $(255\text{-}G)^2 / 2G = f(C)$ and the possibility of correlation of this dependences with spectrophotometric in coordinates A - $(255\text{-}G)^2 / 2G$.

The need to analyze many different objects for the content of germanium requires the development of simple sensitive methods for a preliminary assessment of their content for the correct further selection of quantitative methods.

The developed method for the determination of germanium in the form of AF-12-MGK IA was used and

tested in the analysis of coking coal and iron ore. For analysis, we took coal from the coke-chemical plant in Kryvyi Rih, and iron ore from the Krivorozhskoye deposit. In coke-chemical production, the bulk of germanium remains in coke and only a small amount goes into tar water and tar. Coking coal is one of the sources of germanium production. The correctness of the results was monitored by the standard method (Table 4) using phenylfluorone. Also, the method of verification of model solutions (Table 5).

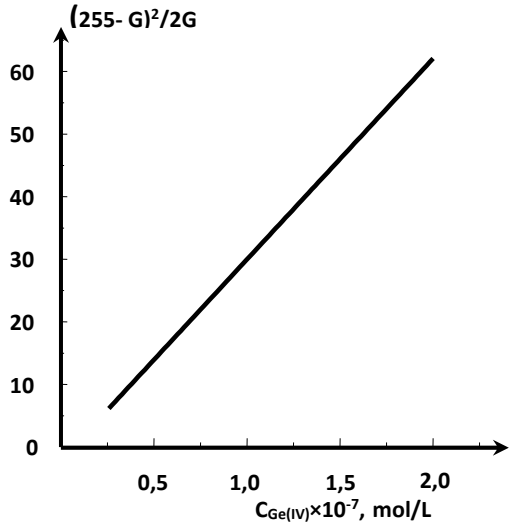

Fig. 4. Calibration chart for colorimetric determination of Ge (IV) in the form of IA KF with 12-MGK. Dependence of the modified Kubelka-Munk function on the concentration of germanium (IV).

Table 4. The results of the determination of Ge (IV), α = 0.95, *n* = 6

object of analysis	**colorimetric determination of IA AF with 12-MGK, discovered Ge ($X_{cp}\pm\Delta$), %(S_r)**	**Standard determination procedure using phenylfluorone, discovered Ge ($X_{cp}\pm\Delta$), % (S_r)**
coking coal	$(2\pm0{,}08)\cdot10^{-6}$ (0,03)	$(1{,}67\pm0{,}06)\cdot10^{-6}$ (0,04)
iron ore	$(1\pm0{,}08)\cdot10^{-6}$ (0,04)	$(1{,}25\pm0{,}06)\cdot10^{-6}$ (0,04)

Table 5. Results of visual-test determination of GeO_3^{2-} in model solutions by the introduced-found method (*P* = 0,95, *n* = 6)

sample	**Introduced Ge ^{IV}, µg/l**	**discovered Ge ^{IV}, ($X_{cp}\pm\Delta$), µg/l**			
		proposed method	S_r	Method with phenylfluorone	S_r
drinking water "Bon Boisson"	58,0	59,4±2,5	0,03	58,5±2,0	0,03
distilled water	14,5	14,7±0,14	0,04	14,6±0,14	0,03

Thus, the possibility of using colorimetry in the analysis is confirmed, but not as a substitute for spectrophotometry, but as an element of preanalysis. In spectrophotometry, integrated spectral characteristics are measured, in colorimetry, the components of color, that is, the color is differentiated into components. These are the so-called primary color coordinates: red (R), blue (B) and green (G) [13].

Calculations of these coordinates, their relationship with the concentration of the colored substance can increase the sensitivity of the determination, recognize shades, find steps for varying the concentrations in the manufacture of visual test scales.

Colorimetry, as a method of objective color measurement with computer processing of data, is widely used in industry: printing, varnishing, textiles, food, pharmaceuticals, and also began to be used in analysis.

At the moment, colorimetry is distinguished as an independent physicochemical research method. Colorimetry can be a powerful tool in material science, visual express analysis. In the literature they give recommendations for constructing color scales. There is an opinion that the minimum step of the scale corresponds to the Golden Ratio (Fibonacci number), the use of which minimizes the error of analysis [14].

Compared to the standard spectrophotometric method using phenylfluorone, the test method using astrafloxin has several advantages:
– is the lower definition threshold
– speed of determination
– greater availability of materials and reagents
– ability to use for on-site analysis
– no need to use expensive equipment.

At the same time, the disadvantages of the test method are:
– less reliability
– the method is semi-quantitative.

Thus, the test method cannot claim to be used in precision research, but can be used for educational research and approximate content assessments of Germanium.

The use of test systems in onsite analysis as part of the training course is one of the elements of sustainable development in learning.

Students gain an understanding the ability to determine micro-quantities Germanium is an important aspect of the eco-chemical assessment of the environmental impact of industrial enterprises. of chemistry for sustainable development as a new approach to the planning and implementation of chemical reactions and chemical processes. He learns that at the planning stage of the experiment, an assessment is needed not only of the target chemical properties of the future product, but also an assessment of environmental risks.

Currently, this method of the semiquantitative determination of germanium is used in laboratory and chemical practice at the Kryvyi Rih State Pedagogical University. As part of the analysis in place. The experience of use showed the simplicity and accessibility of performing operations to prepare a test scale and subsequent colorimetric analysis.

During the chemical training students studied the water of various reservoirs (including man-made ones)

of the city of Kryvyi Rih and surrounding areas. The study was conducted on many parameters, including the definition of Germanium. Germanium is a potentially dangerous element for human health [15].

However, the results of research over the last 5 years show that the content of Germanium, even in man-made reservoirs, does not exceed 1 μg/l. This is due to the rather low mobility of inorganic compounds in Germanium. It also shows that there is no potential environmental threat from Germany in such an industrial region as the city of Kryvyi Rih.

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The hypothesis about the influence of electrical phenomena on geological processes and global disasters

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Abstract. Global Warming is officially recognized as one of the aspects to the Earth's climate change; and its major factor is a sharp anthropogenic increase in concentration of greenhouse gases, especially carbon dioxide (CO_2). However many scientists do not agree with this view and do not consider the anthropogenic factor as its basic reason, thus regarding measures for limiting greenhouse gas emissions as useless. The authors believe that a real reason is lack of unequivocal ideas in the framework of the Earth Science. The objective of the research presented in the article is to establish true reasons for global catastrophes, global warming, their rapid increase of recent decades, and their hazard level, as well as to reveal their nature and actual mechanisms. The authors critically analyzed and compared the existing data on global processes and catastrophes on Earth from ancient times to nowadays, revealed their actual mechanisms on the basis of Submicro- and Macrocolloid Chemistry and Physical-Chemical Mechanics of Earth, a new science on Earth set up by the authors. The authors demonstrated that the motive power of all global phenomena and processes on Earth is the electric force, conditioned by the surplus negative electric charge of Earth, and the reason of the approaching global catastrophe is an abnormal increase of the charge in recent decades. The article deals with critical analysis of experimental data on dynamics of global catastrophes, among them the change in Earth's temperature and level of ocean, a greater amount of carbon gas and atmosphere dust.

1 Introduction

Global Warming is officially recognized as one of the aspects to the Earth's climate change; and its major factor is a sharp anthropogenic increase in concentration of greenhouse gases, especially carbon dioxide (CO_2). Global warming mainly manifests itself as a rapid increase in Earth's temperature, a change in the warm Gulf Stream current, etc. of last decades. International treaties recognize that the key measure to prevent the warming is compulsory reduction of greenhouse gas emissions, which consumes huge funds and physical recourses. However, many scientists do not agree with this view and do not consider the anthropogenic factor as its basic reason, thus regarding measures for limiting greenhouse gas emissions as useless. Many people can realize the approaching catastrophe but they do not know how to resist and what they should do. According to some researchers the reason of global warming is lack of veritable knowledge about the world and man. We believe that a real reason is also lack of unequivocal ideas in the framework of the Earth Science.

Unlike the existing science and "alternative" sciences, the authors established an actual reason and revealed the mechanism of these global cataclysms and natural disasters, revealed mechanisms of the Earth development and imminent global catastrophes, and, furthermore, critically analyzed existing experimental data on the global catastrophes' dynamics.

In recent decades the number of natural disasters in the world has rapidly increased.

It is considered that the reason is in the Earth's global climate change, in particular, a higher temperature and the anthropogenic increase in the greenhouse gas concentration since 1960, especially CO_2 and methane (CH_4), (it is shown in Fig. 1 as the first maximum), a change in the warm Gulf Stream current, etc. As it was mentioned above, international treaties (the Kyoto Protocol of 1999, the Paris Agreement of 2015) consider a compulsive reduction of greenhouse gas emissions as the key measure to prevent these catastrophes; therefore, this requires great funds and physical recourses.

However, there are some other views on the problem. As many scientists think, particularly in [1-3], Earth's global warming has not been caused by the CO_2 emissions to the atmosphere, but, on the contrary, by a higher temperature of Earth; as there is no record about anthropogenic contribution into an average annual temperature rise on Earth, we can suppose that the international treaties are not practical and rather useless. We believe that the reason is lack of the genuine knowledge about the world and man, and, actually, the erroneous nature of the Earth Science.

2 Research methodology

The methodology of the research is based on Submicro-

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and Macrocolloid Chemistry and Physical-Chemical Mechanics of Earth, a new science established by the authors that was published in book "Submicro- and Macrocolloid Chemistry and Physical-Chemical Mechanics of the Earth" in 2016. The science is based on laws and regularities of Colloid Chemistry and Physical-Chemical Mechanics of Dispersed Systems and applied to subjects of inquiry of the submicro- and macrocosms. Their applicability is conditioned by the fact that Colloid Chemistry and Physical-Chemical Mechanics [4, 5] considers the surface phenomena, in particular, electrosurface characteristics of disperse systems. Earth is also considered a disperse system, with a scale of <10 Å and >>1 μm, going far beyond the colloid sizes (10 Å ÷ 1 μm), where electrical surface phenomena, processes and regularities are also prevalent.

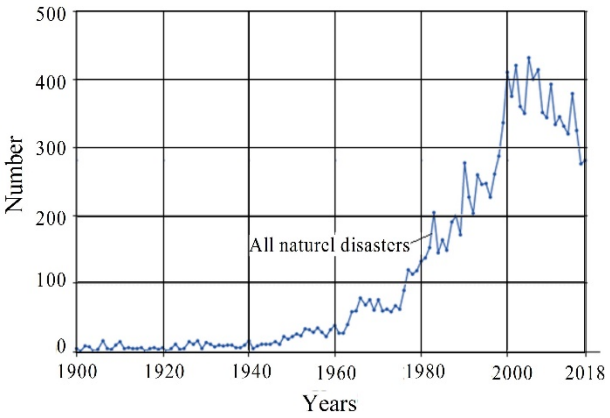


Fig. 1. Number of reported disaster events: drought, floods, extreme temperature, landslides, wildfires, volcanic eruptions, earthquakes and other. *Source*: EM-DAT (2019): OFDA/CRED International Disaster, Universite catholique de Louvain- Brussels-Belgium.

The used methods are theoretical and analytical and based on generalization and critical analysis of existing literature data in the field of global phenomena and processes on Earth. Regularities that are used for analysis: Coulomb electrostatic forces, polarization, diffusion, osmosis, capillary rise, etc.

3 Analytical review

Previously, the authors on the basis of the provisions of colloid chemistry and physico-chemical mechanics have studied the electrical effects on building structures and materials. For example, the construction of electrified railways, which are operated under the conditions of electrical influences from sources of direct [6] and alternating current [7]. It was shown and experimentally proved in [6] that under the influence of a pulsating unidirectional electric potential and the corresponding current flowing during the passage of trains, concrete and masonry mortar also undergo electrocorrosion. Electrocorrosion consists in electromigration leaching of $Ca(OH)_2$ [6] and the formation of cracks [8-10], the intensity of which depends on the current strength [6]. It was shown in [6, 10, 11] that the electrical effects on concrete and structures made of it are not only electric potentials and leakage currents, but also excess electric charges. Excessive charges are formed during the macro-polarization of objects, both artificial and natural, from the unevenness of the Earth's electric field on the ground, from the transfer of cations of soils, rocks and concrete by ground and underground waters, temporary and permanent streams. Based on electrical measurements, schemes have been developed for the flow of leakage currents from rails of an electrified direct current railway track through structures that are in good agreement with the nature of corrosion damage. The effect of excess electric charges on the decrease in tensile strength of concrete [10], the deterioration of the physical and mechanical properties of soils as a result of their liquefaction [11] was experimentally confirmed.

Based on the understanding of these phenomena and processes, means have been developed to protect structures from electrical influences in the form of anodic or cathodic electrochemical protection, electro-drainage [12], grounded electrically conductive screens [6] or screens made of electrically conductive compositions based on mineral binders [6, 13] with simple or diode grounding, which drains leakage currents and stray currents. To protect structures from such currents it was proposed in [14, 15], to use screens-coatings with a polymer-cement mortar with increased electrical resistance, which will impede the flow of currents through the structure or reduce their strength.

By analogy with the proven regularities of electrical effects on building materials and structures, as well as the soil of the foundations, a hypothesis is put forward on the effect of electrical phenomena on geological processes and global disasters.

4 Results of research

On the basis of Submicro- and Macrocolloid Chemistry and Physical-Chemical Mechanics of Earth the authors revealed mechanisms of global phenomena and processes on Earth, such as a rapid growth in the number of natural disasters and catastrophes of recent decades, a higher temperature and greenhouse gasses (global warming), change of the warm Gulf Stream current, etc. In order to reveal these phenomena and processes and estimate their hazardous degree for the present civilization, the authors generalized and critically analyzed the global cataclysms and processes of ancient times, namely, the change in global temperature, the Sun's activity, greenhouse gasses, atmosphere dust, ocean level, extinction (or rather, disappearance) of organisms and humans, formation of supercontinents and their disintegration into continents, etc.

The moving force of the mechanisms and other phenomena and processes on Earth and beyond is the electric force induced by the surplus negative electric charge of Earth, and the reason of the approaching global catastrophe is an abnormal rise of this charge in recent decades.

The basic source of the charge is the thermal diffusion of electrons from the molten Earth's core as a result of a very big difference of temperatures in Earth's core (about

6000 °C) and on Earth's surface (14°C on the average), Fig. 2.

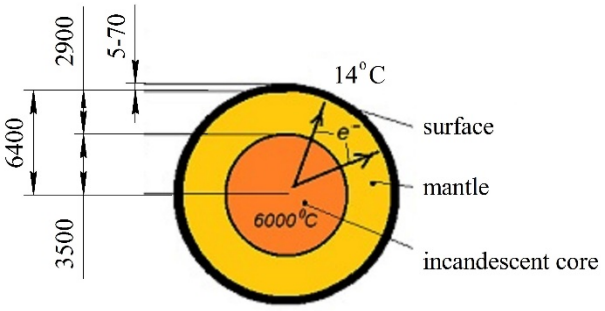
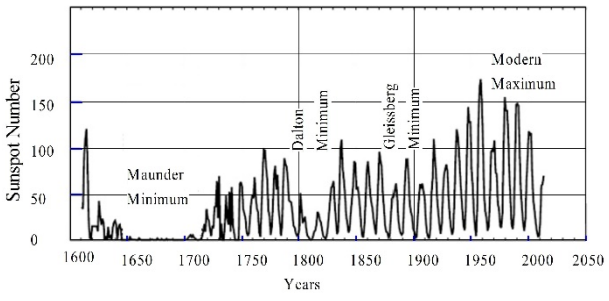


Fig. 2. Diagram of the excess negative charge of the Earth due to thermal diffusion of electrons from its red-hot nucleus to the surface

Such a notion of the surplus negative charge of Earth correlates with a diagram of Earth's spherical capacitor reproducing the hypothesis on ionosphere put forward by Nikola Tesla. It creates in the upper layers of Earth and its atmosphere the electric field, with the experimentally found average potential E = -130 V/m (corresponds to the equilibrium surplus negative charge), and near Earth's surface it changes from -1000 to +200 V/m.

Very intensive sources of Earth's surplus negative charge are also the Secular Sun's Activity and the periodic 11-year Sun's activity, Fig. 3, a.

In recent decades the most intensive source of the surplus negative charge has become space launchings (since 1957), from Cape Canaveral Air Force Station, the John F. Kennedy Space Center and the Wallops Flight Facility, mass launches of the super heavy Space Shuttle systems, and also Chinese rockets (Fig. 3, b, c and d, respectively). During the launch of a rocket, especially a heavy one, and the combustion of rocket fuel, a significant separation of electric charges occurs between the earth and the upper atmosphere.



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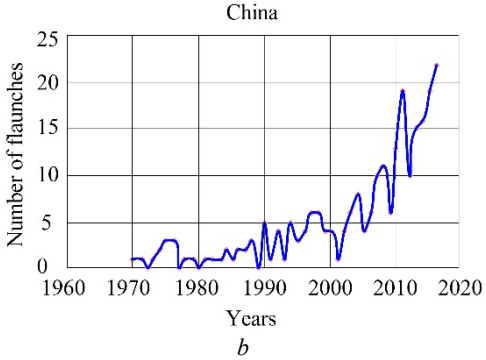

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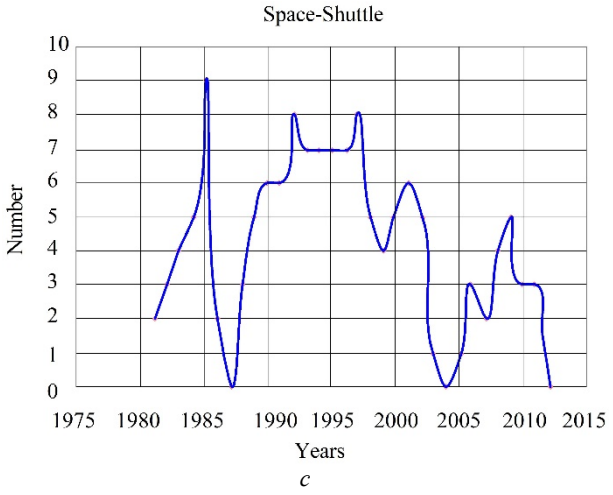

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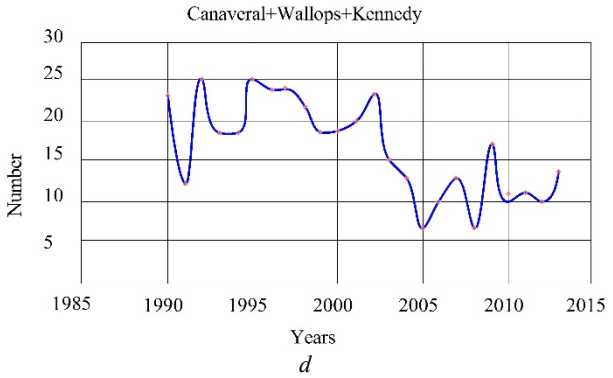

d

Fig. 3. Space rocket launches: a – the Secular Sun's Activity and cycles of the 11-year Sun's activity. Compiled by [1]; b – rocket launches of 1970-2017 by China; c – rocket launches the Space Shuttle systems in 1981-2012; d – rocket launches from Cape Canaveral Air Force Station, the John F. Kennedy Space Center and the Wallops Flight Facility.

5 Mechanisms of the earth development and increasing global catastrophes

Let us consider mechanisms of basic processes and phenomena of the Earth development and imminent global catastrophes. The Earth's evolution has been accompanied by catastrophic processes for all living beings.

The surplus negative charge as the motive force for absolutely all global processes became apparent from the formation of Earth at least 5.5 billion years ago. Earth was formed when part of the accumulated surplus charge of the Sun as a molten mass corresponding to Earth's mass emitted to the Earth's orbit; it was provoked by thermal diffusion of electrons of the Sun (in the core the temperature is about 10,000,000,000 °C and outside – 6,000 °C).

About 1.4 billion years later in the cosmic vacuum with a temperature of 2,725 K (about -270 °C) the Earth surface with the world ocean became cool to the normal temperature and the first supercontinent Vaalbare appeared, Table 1.

Then, due to the constantly running thermal diffusion of electrons, a huge surplus negative charge accumulated under Earth's crust, the crust of the supercontinent

softened and fractures developed in it. These fractures accumulated the surplus negative charge of a very high concentration thus separating formed parts of the supercontinents great distances apart. And the supercontinent split into continents. It took about 100 million years.

Table 1. Formation of Supercontinents of Earth.

No	Supercontinents and Continents, years (billion/million years ago)	Beginning of existence (disintegration duration)
0	Earth, 4-5	
1	Vaalbara, 3.1-– 2.8	1.4
2	Kenorland, 2.7 – 2.5 (disintegration)	0.4 (0.1)
3	Nuna (Columbia), 1.8-– 1.5	0.9 (0.7)
4	Rodinia, 1.1 – 750 (disintegration of the previous one)	0.7 (0.4)
5	Pannotia, 600 – 540 (disintegration)	0.5 (0.15)
6	Pangaea, 300 – 180	0.3 (0.24)
7	Present Earth, 65	0.235 (0.115)

All these transformations of supercontinents and continents went along with influences of gigantic forces and cataclysms, when life could not exist yet. For the first time, as known, about 525 million years ago living beings appeared, and animals, such as amphibian and reptiles, about 300 million years ago, Fig. 4.

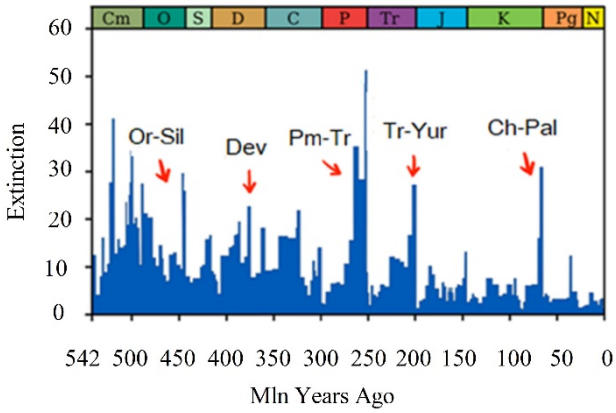

Fig. 4. The great extinctions of organisms on Earth during the period from 542 million years BC to present [16].

During their life the organisms regularly died out and disappeared, it might happen even on a massive scale:
1. The Ordovician–Silurian extinction events, 440 billion years ago (got extinct more than 60% of sea invertebrates).
2. The Late Devonian extinction, 380 million years ago (the number of marine communities reduced by 50%).
3. The Great Permian Extinction, 265 million years ago (got extinct more than 95% of all living organisms).
4. The Triassic-Jurassic extinction event, 210 million years ago (died out more than 50% of all types of living organisms known at present).
5. The Cretaceous-Paleogene, 65 million years ago (died out dinosaurs and 70% of all types of living organisms).

Life on land and relatively big animals appeared in the Carboniferous period. It is believed that the man appeared 2 million years ago.

Virtually all ancient developed civilizations, and there were several of them, disappeared. Nevertheless, they left for us megalithic structures build in recent ten-twenty millenniums, whose construction technologies cannot be applied at present.

One of the reasons why animals and people died out is also considered the constantly recurring Ice Ages or Glacial Periods (millions of years in duration).

Thus, the analytical research, presented in this section, confirmed that Earth's global processes (extinction of living organisms and people, and, consequently, vegetation, formation of continents and glaciers, orogenic processes, etc.) were chiefly caused and regulated by the periodically accumulated and dropped a huge surplus negative charge in the Earth's surface layers.

The fact, that most types of people ever lived on Earth became extinct, affords ground for a number of researchers to assume that all types of life have a limited period, and human extinction is inevitable (i.e. mankind always runs risk to die out) [17].

The significant factors of the global climate change on Earth are considered a rapid increase in temperature and greenhouse gasses, first of all, CO_2, and a change in the Sun's activity, Fig. 5.

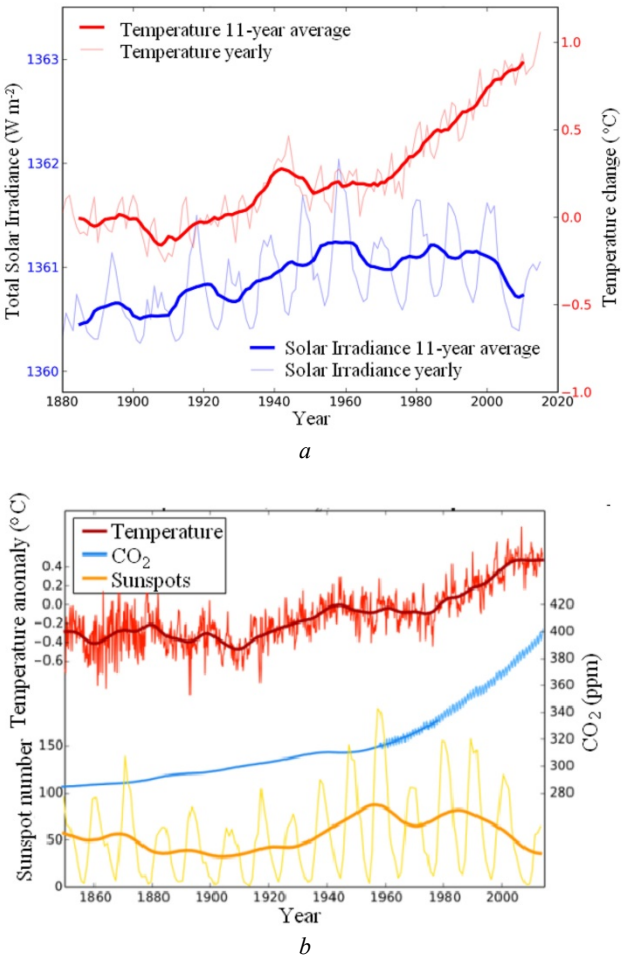

Fig. 5. Annual global temperature, Solar Irradiance and CO_2 change: a – compiled by Solar vs TemperatureSkeptical Science; b – schedule from Global Warming - Research IssuesStanford Solar Center.

Furthermore, "… last several hundred years the number of sunspots has constantly grown, and Earth has become warmer...", however since 1980 such a pattern has broken. Consequently, the Sun cannot be the main temperature regulator.

The relation between the Earth temperature, CO_2 concentration, and the number of sunspots testifies to their increase in concord and in cycles (Fig. 5). And diagrams in Fig. 6 presenting the last 400 and 800 thousands of years, based on diagrams from ice cores from Antarctica confirm it.

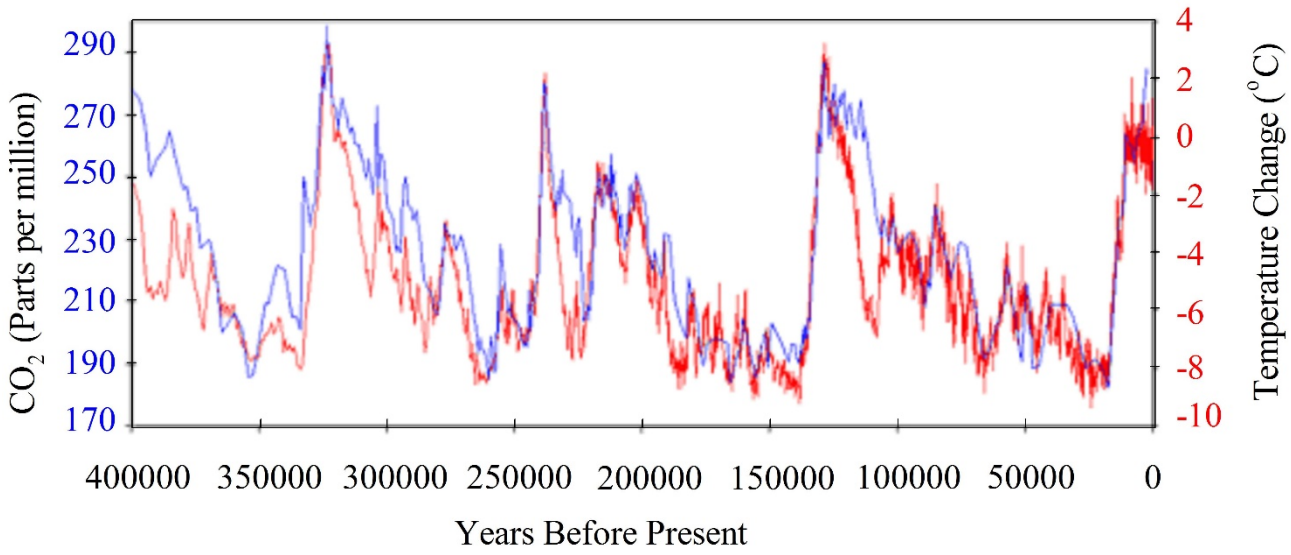

Fig. 6. Vostok ice core records for carbon dioxide concentration and temperature change (CO_2 lags temperature – what does it mean? Skeptical Science).

However, the concentrations have never reached such high values as we can witness today; this fact gives rise to serious concern of many researchers, Fig. 7.

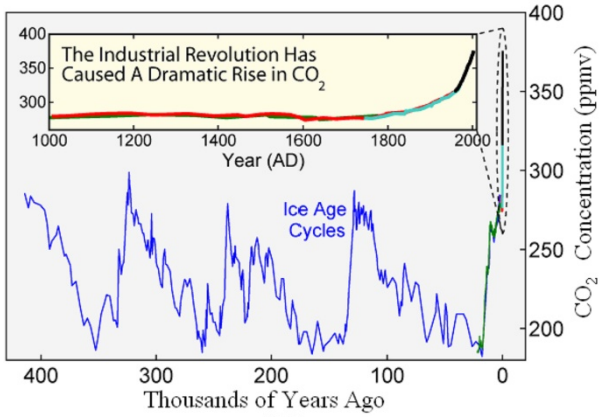

Fig. 7. The change in the content of carbon dioxide (CO_2) during the last 400 thousand years and to present.

According to [18] "… the shape of a temperature curve advances the curve presenting the CO_2 changes by approximately 5-8 thousand years at the time when waters of the world ocean, the main reservoir of free CO2 on Earth, completely got mixed (now the world ocean has approximately 60 times more of CO_2 dissolved than that in the atmosphere)".

According to diagrams presented, the concentrations of carbon dioxide (as methane) fluctuated in right cycles with a period of about 100,000 years. However, a more attentive study reveals that the CO_2 change actually follows the temperature change, with a delay close to one indicated.

The global temperature growth was also followed by an ocean level fall to approximately 100 m, Fig. 8.

The indicated periodic change in carbon dioxide (CO_2) due to its greater content in the ocean is conditioned by an increase in the surplus negative charge in the surface layer of the ocean water. It results in better solubility and increased concentration of CO_2 (mostly hydro carbonates and bicarbonates) in the ocean waters when CO_2 transfers to the atmosphere). A decrease in the surplus negative charge leads to crystallization of solution products. Accordingly, an increase or a decrease in the surplus negative charge during a long period (100 thousand years in average) leads to a cyclic long-term change in the temperature.

Accumulation of the surplus negative charge in Earth in recent decades, and thus, Earth's warming is the result of excessive rocket launches; and this leads to another Global catastrophe on Earth. Here, we can conclude that the CO_2 input into the atmosphere is not anthropogenic by nature, but the cause of Earth's warming is a huge increase in the surplus negative charge.

By the way, with an increase in the surplus negative charge in the ocean waters, not only CO_2 transfers to the atmosphere, but also the water itself; it happens due to its much more intensive evaporation, therefore water vapor is the most powerful greenhouse gas.

The data on long cyclic changes in both the amount of dust in the atmosphere and temperature cycles in ancient times and now obtained from ice cores of Antarctica are of considerable importance for studying Earth's global cataclysms, Fig. 8, Fig 9.

Such a substantial fall of the ocean level was conditioned by the previous rapid increase in the surplus

negative charge of Earth, which raised the ocean and sea waters along the soil capillaries by the macro electroosmosis mechanism, thus lowering the ocean water level.

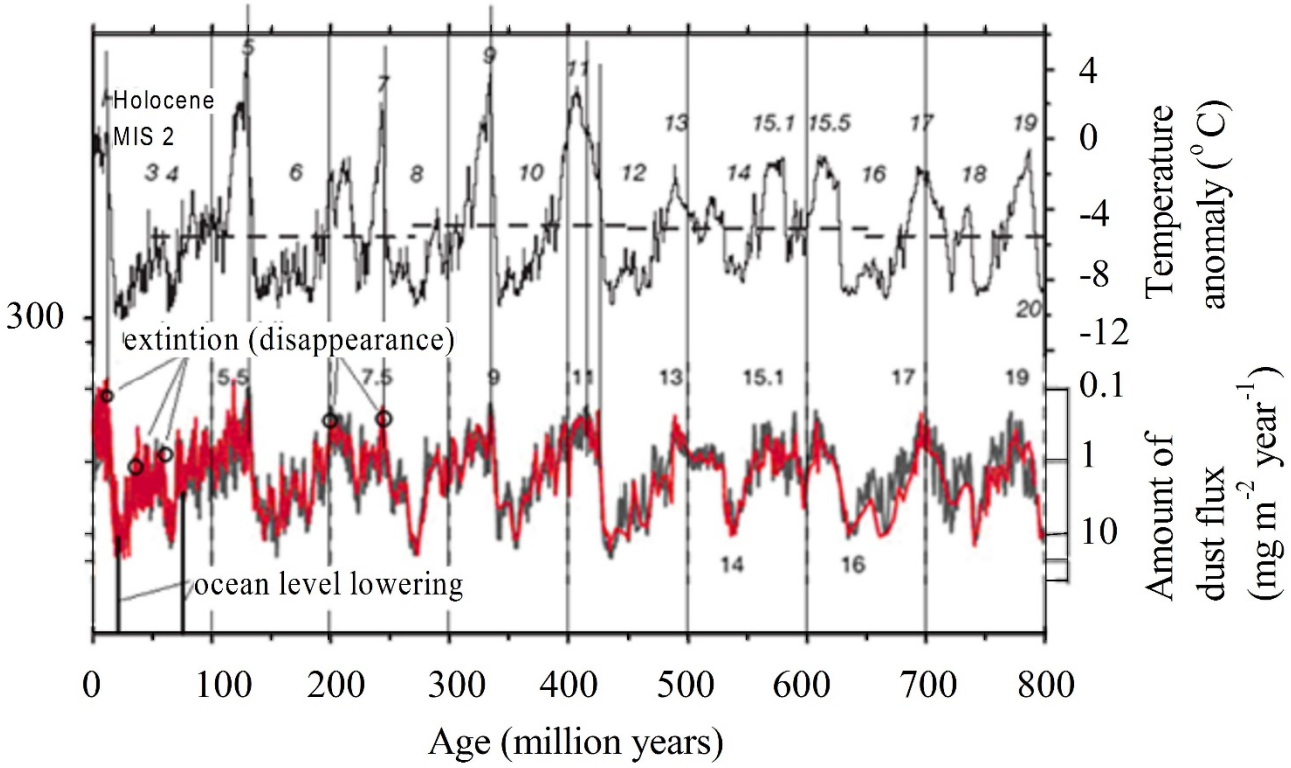

Fig. 8. The long cyclic changes in temperature and amount of dust in ice cores (atmosphere) during 800 million years (based on diagrams of [19] and [20]).

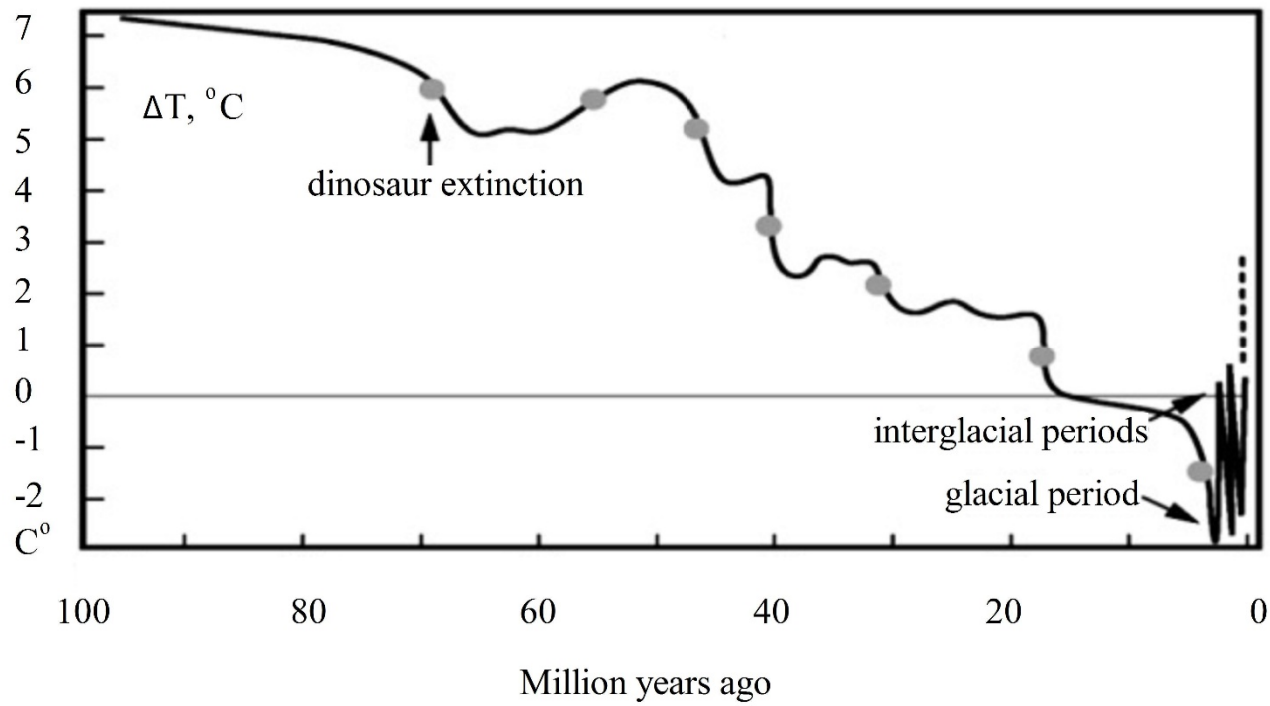

Fig. 9. The change in Earth's temperature from 100 million years ago to 0.5-3.5 billion years ago (the diagram is corrected by the period of dinosaur extinction – 65 million years ago) [16].

The surplus negative charge accumulated on soil and soil particles repulsed, the soil became loosened and atomized, and lost its cohesion. Their large surplus negative charge led also to emergence of repulsive forces to the large negative charge in the Earth's surface layer. This force exceeded the gravitational force, and then the soil particles and the surface layer tore off and carried along virtually everything off the surface.

At earlier stages of its existence (0.5-2.25 billion years ago) the Earth temperature was about 25-47 °C with the maximum 1.75 billion years ago [21], which was quite acceptable for the beginning of life, especially in ocean. And in the earliest years of its existence, 2.25-3.5 billion years, the temperature was considerably higher, up to 70 °C, which was incompatible with life of most living organisms. The minimal temperature of 5 °C (about 65 million years ago) in the diagram (Fig. 9) when dinosaurs disappeared, coincides with the minimal ocean level (Fig. 8). Apparently, the second maximum ocean level (450 million years ago), Fig. 10, also coincided with the maximum temperature, this tendency manifested itself as the beginning of a temperature rise 500 million years ago.

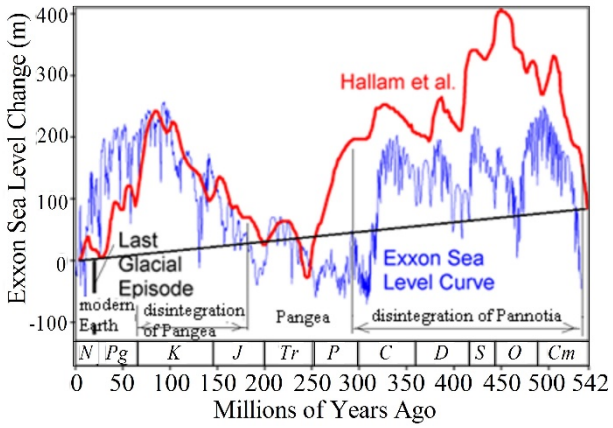

Fig. 10. The change in the ocean level during the period from 540 million years ago (based on the diagram of [20]).

Such a change pattern in Earth's temperature and ocean level confirms that originally the surface temperature was very high, i.e. incompatible with any life on Earth. Approximately by a period of 1.5 billion years ago, the surplus charge of Earth reduced and reached the equilibrium state. Then it began to change in cycles relative to this equilibrium. The maximum negative charge resulted in global catastrophes, and then the surplus negative charge fell and began to rise again due to thermal diffusion of electrons from the Earth's core.

As we can see, the greatest changes in the ocean level coincide with periods of existence of the supercontinents (here, Pannotia and Pangaea, Table, the minimal level) and their disintegration (the maximum level). The mechanism of their disintegration and formation is based on this dependency.

The main role of the surplus negative charge in all the global catastrophes is also confirmed by formation and disintegration of the supercontinents. During all its life the supercontinent accumulated a huge surplus negative charge underneath, and gigantic stretching forces grew in it. Moreover, the soil of the continent became softer, and the surface layers became loosened, crumbled up and dusted. When the stretching forces reached the limiting values, thus exceeding the supercontinent strength, cracks and splits developed inside, they accumulated a huge surplus negative charge from Earth's core; then the split parts went apart and formed continents.

Enormous amount of dust elevated off the Earth surface that was incomparable with the dust from eruption of the greatest volcanoes, the sunlight could not reach Earth for many million years, and the Earth temperature gradually fell. The cyclic changes in temperature and dust in ice cores of Antarctica convincingly demonstrate it (Fig. 8).

With the lapse of time the enormous surplus negative charge began to accumulate under and inside the formed continents owing to thermal diffusion of electrons from Earth's core. The charges and continents were polarizing acquiring the sequential unidirectional gigantic macro dipole moments towards the equator (due to a lag between the space vacuum and ocean water, and the Earth rotation (and the land on)), as well as in Earth's electric field between the poles. The attraction forces between these dipole moments redistributed the continents; the supercontinents joined and formed the supercontinent Pangaea (Fig. 11).

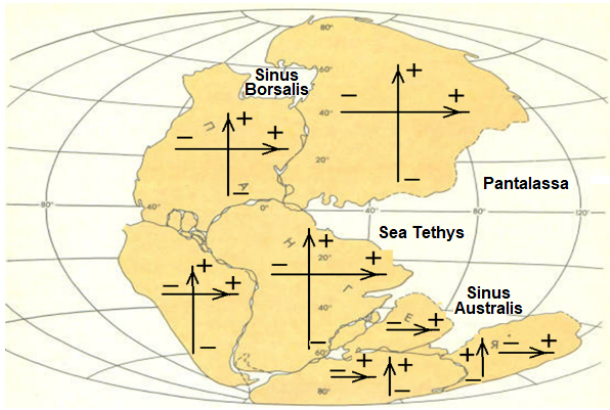

Fig. 11. The continent polarization and huge dipole moments of the continents the attractive forces between which resulted in the formation of the supercontinent Pangaea.

A huge growth in the number of global catastrophes in recent decades, as it was mentioned above, has been conditioned by space rockets launches. The enormous number of these launches and launches of super heavy rockets to the Moon and Mars planned threaten to ruin the civilization in the short run.

6 Conclusions

1. Based on the provisions of colloid chemistry and physico-chemical mechanics of disperse systems and materials, a hypothesis has been put forward about the influence of electrical phenomena on geological processes and global catastrophes.
2. It is assumed that one of the moving forces of geological processes and global catastrophes is the excess negative electric charge of the Earth cyclically accumulated as a result of macropolarization phenomena.
3. The increase in the number of global disasters in recent decades has been influenced by space rocket launches. This effect is due to the fact that as a result of the combustion of rocket fuel, rocket take-off, a significant amount of electric charge is transferred, and it is divided between the earth and the upper atmosphere. A further

increase in the number of launches and mass of rockets may lead to an increase in the number of catastrophic events.

4. The prevention of catastrophic events is possible based on an analysis of the causes of the accumulation of excess charges, the development and implementation of ways to prevent such accumulation.

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Infrared spectroscopy as the method for evaluating technological properties of minerals and their behavior in technological processes

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Abstract. Infrared spectroscopy (IR) is a highly effective method for the analysis of minerals, rocks and ores, capable of solving a whole range of problems when choosing innovative solutions for the technological processing of various types of mineral raw materials. The article considers the main directions of using the infrared spectroscopy method in assessing the technological properties of minerals and their behavior in technological processes: evaluation of the grade (quality) of mineral raw materials; analysis of the behavior of minerals in the technological process with prediction of their technological properties; analysis of changes in the structure and properties of minerals in technological processes; operational analysis of mineral substances at various stages of technological processing. The article illustrates all aspects of the use of infrared spectroscopy at various stages of studying the material composition of mineral raw materials in its enrichment assessment by specific examples of solving problems arising from the technological redistribution of various types of ore and non-metallic minerals.

1 Introduction

The modern stage of mineral processing is characterized by the involvement of increasingly poorer and more difficult-to-concentrate ores in the technological process. In this regard, there is a need for deeper study of their material composition at the level of recent advances in the field of crystal chemistry and crystal physics of minerals with the involvement of a wide range of the latest physical and chemical methods of analysis.

Infrared spectroscopy (IR spectroscopy) has been widely used in recent years in the practice of geological exploration. First of all, this is due to the high resolution of the method, its quickness, versatility and economy. The advantages of IR spectroscopy are most fully shown when studying the crystal chemical features of minerals such as polymorphism, isomorphism, coordination, and the degree of deformation of structural polyhedra. Considering the fact that these attributes are most widely demonstrated in the technological properties of minerals [1], it can be assumed that this method must take its rightful place in a wide arsenal of physical and chemical methods of analysis used for assessing the behavior of minerals at different stages of technological processing of ores of various types of minerals.

2 Publication overview

Nowadays the literature contains quite a few examples of the use of infrared spectroscopy in studies of various types of mineral raw materials in order to increase the efficiency of their technological processing. This research currently develops in two directions: geological-mineralogical and technological. Representatives of the former direction (V. Farmer [2], T. Shishelova [4], B. Pirogov [1, 6, 7, 9], A. Ivanov, J. Kloprogge, D. Kamalova [18], E. C. Hecker, A. Remizov [14], R. Skochilov [18], I. Suvorova, N. Batyrshin, V. Stolpovskaya [18], A. Fishman [18], A. Smith [20], R. Frost [26-28], E. Malinowski [30], and the others) reveal signs that determine technological properties of rocks and ores when using infrared spectroscopy to diagnose qualitative and quantitative phase analysis of them, and establishing the crystal-chemical features of minerals. The technology research (Yu. Batura [10], B. Rivard, A. Jones, J. Miller [11], R. Clark [19], A. Guatame-Garcia [24], M. Buxton, R. Bedell [24], J. Kellar, R. Lima, P. Brandao, E. Giesekke, I. V. Solnyshkin, V. Chanturia [16, 22], I. Plaksin [25], etc.) are mainly based on the study of surface phenomena using infrared spectroscopy when fixing flotation reagents to minerals, as well as changing their properties under various external influences (thermal, radiation, ultrasound, etc.).

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The aim of the article is to analyze and generalize the available published data of the IR spectroscopy method in assessing the technological properties of minerals and their behavior in technological processes of ore processing.

3 Methods

The results of the author researches served as the real material of the article, the analysis of a number of the analogous works of the other authors was also presented. The IR-spectra study of minerals, rocks and the enrichment's products was made on the two-rays spectrophotometer Specord of "Carl Zeiss, Jena" firm (Germany) by the method of paste in the refined petrolatum oil. The intensity of the absorption's stripes was measured, according to the method of the basic line. The hardness of minerals was defined by the method of pressing on the PMT-3M hardness micrometer, but the dielectric penetration – by the sensor of Petrzhyk. The content of the elements in minerals and products of the enrichment was determined by the method of the chemical analysis.

4 Results

Analyzing the information available today, we can say that infrared spectroscopy can be widely used at various stages of studying the material composition of mineral raw materials while assessing its enrichment; and it can solve various tasks of technological ore processing. Let us consider in detail the main ones.

4.1 Assessment of grade (quality) of mineral raw materials

One of the main characteristics of mineral raw materials is a combination of properties that determine compliance with its purpose. The separation of minerals into varieties plays a leading role in assessing the level of its quality.

IR spectroscopy is one of the most effective physical methods for assessing the grade of mined non-metallic mineral raw materials. Thus, studies of phlogopites ($K\,Mg_3\,[Al\,Si_3\,O_{10}]\,(F,\,OH)_2$) from the Kovdor phlogopite-vermiculite deposit (Russia) showed that the infrared spectra of phlogopites enable to estimate their properties, including those that determine their quality or technological grade.

It was established [2] that phlogopites of various genetic types contain absorption bands with a maximum of 3700, 3660, 3620, 3550, and 3400 cm^{-1} in the region of stretching vibrations of OH groups. Typomorphic are mainly bands of 3550 and 3400 cm^{-1}. Absorption in the region of 3550 cm^{-1} is characteristic of multimolecular layers. They are quasi-solid structured entities. The band in the region of 3400 cm^{-1} corresponds to stretching vibrations of water in the bulk phase, the so-called film water [3].

Consequently, we have revealed the relationship between the intensity of these absorption bands and the physical properties of the phlogopite of the Kovdor phlogopite-vermiculite deposit. So, Fig. 1 clearly demonstrates that the increase in the absorption coefficient at the maximum of the bands of 3550 and 3400 cm^{-1} leads to the decrease in the hardness of phlogopite, as well as the decrease in the dielectric constant of the mineral. T. Shishelova and co-authors [4] obtained similar data for phlogopites from deposits in Siberia (Russia).

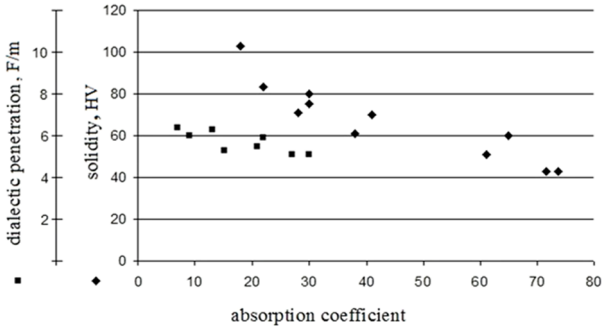

Fig. 1. The relationship between the intensity of the bands of 3550 cm^{-1} and 3400 cm^{-1} of the IR spectrum of the phlogopite of the Kovdor deposit and its physical properties.

ICS method acquires the particular importance in assessing the grade of gemstone raw materials. The quality of a gemstone depends on many parameters, among which the most essential is the chemical composition and impurities.

Figure 2 shows the infrared spectra of aquamarines ($Be_3Al_2Si_6O_{18}$) of various grades. As can be seen from the above IR spectra, the region of stretching vibrations of OH groups of aquamarine depends on the grade of the raw material. Class 1 aquamarine has almost no absorption bands in the region of stretching vibrations of OH groups. As for class 2 aquamarines, we observe absorption in the region of ~ 3640, 3580 cm^{-1}. Class 3 aquamarines have a wide absorption band with a maximum frequency of 3400 cm^{-1}, which is characteristic of free water. This is clearly expressed in the spectra of low grade aquamarine and is associated with the presence of defective sites where free and surface water is adsorbed. The presence of defective places affects the quality of the mineral. The same regularity is also characteristic of the region of deformation vibrations OH (υ = 1620 cm^{-1}) [5].

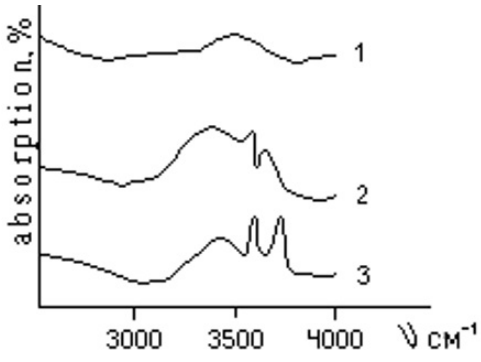

Fig. 2. The infrared spectra of aquamarines ($Be_3Al_2Si_6O_{18}$) of various grades [4]).

The revealed relationships allow us to provide an operational analysis of the grade of phlogopite raw materials. The operational analysis can be performed both on the basis of geological and technological testing and mapping of deposits, and as a result of selective express analysis in the process stream.

The selection of grades of mineral raw materials is often determined by its phase composition. For example, the possibility of using baddeleyite (ZrO_2) for the production of glazes is determined, first of all, by the concentration of phosphorus impurities. With its increased content, the glaze becomes dull, which reduces the quality of colored ceramic tiles. The presence of phosphorus in the baddeleyite concentrate of the Kovdor baddeleyite-apatite-magnetite deposit is determined by the presence of micro impurities of apatite (Ca_5 $[PO_4]_3$ (F, Cl, OH)) in it. The content of P_2O_5 in the concentrate ranges from 0.05 to 0.93 %.

Apatite in baddeleyite concentrate is traced by the presence of information absorption bands in the regions of 640 and 670 cm^{-1} in the infrared spectrum of baddeleyite. They are responsible for the librational vibrations of the hydroxyl group of apatite. Figure 3 shows a histogram of the distribution of the intensities of the 670 cm^{-1} band in the spectra of 56 samples of baddeleyite monofractions. The whole sample is clearly divided into two groups. The right maximum corresponds to samples with a high content of apatite micro impurities (P_2O_5 content exceeds 0.54 %) which belong to the grade of substandard baddeleyite confined mainly to the zones of superimposed apatitization of ores of apatite-forsterite-magnetite composition. The left one corresponds to the samples with minimum apatite content suitable as a raw material for the production of glazes.

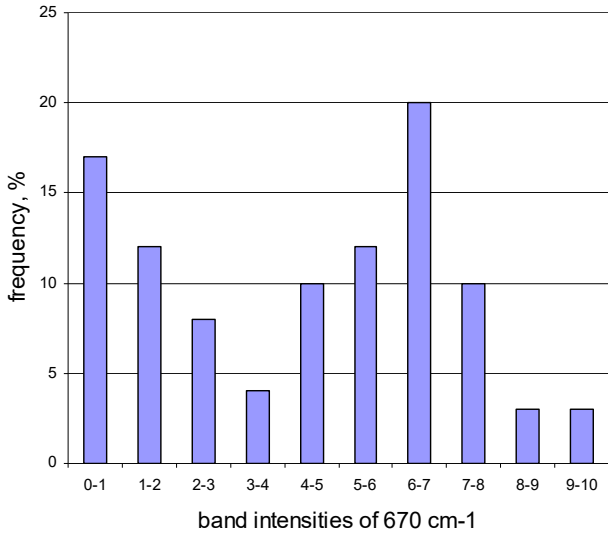

Fig. 3. Histogram of the distribution of quantities band intensities of 670 cm^{-1} in the spectra of mono-baddeleyite fractions of the Kovdor field.

4.2 Analysis of the mineral behavior in the process with prediction of their technological properties

For the efficient processing of mineral raw materials, it is extremely important to study the behavior of the entire complex of minerals (composing ores) at the technological stages of processing, such as crushing, grinding, separation, etc. Real minerals behave differently in technological redistribution because of defective structures, the presence of numerous impurities and inclusions. The task of researchers to control all these aspects, making recommendations for improving the processes of enrichment using a wide range of physical and chemical methods for the analysis of minerals and ores. So, it becomes possible to solve the problem of leading forecasting of technological indicators of ore processing.

For example, the crystal-chemical features of magnetite data obtained through IR spectroscopy are of fundamental importance for solving various problems of the magnetite ores enrichment. First of all, it makes possible to obtain data on assessing the balance of redistribution of useful and harmful elements-impurities in magnetite ($FeFe_2O_4$) upon receipt of iron ore concentrate [6], revealing the form of their occurrence.

For example, the infrared spectra of magnetites of the Gusevogorsky deposit are characterized by a similar texture type of mineralization (medium disseminated ores), but significantly different technological enrichment indicators. A shift of the ν_3 band to the low-frequency region 564 → 545 cm^{-1} is noted (Fig. 4). The position of this band depends on the composition of the mineral and varies over a wide range from 526 cm^{-1} for hematite, which can be fixed as a product of magnetite oxidation, up to 575 cm^{-1} for stoichiometric magnetite [7]. IR spectroscopy unambiguously indicates an increase in the internal heterogeneity of Gusevogorsk magnetites. Particularly, the manifestation of isomorphic substitutions of Fe^{+3} for Ti^{+4} and the decomposition structures of magnetite-spinel, magnetite-ulvospinel solid solutions reduce the iron content in magnetite concentrate by more than 2 %.

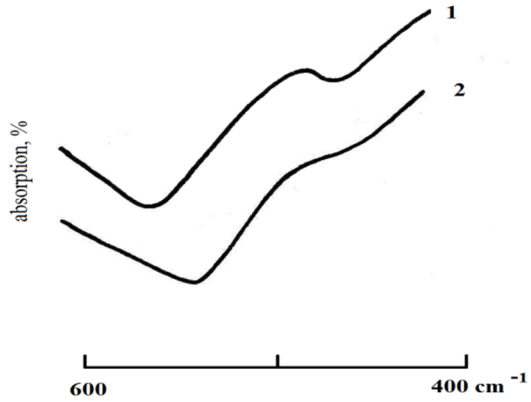

Fig. 4. The change in the position of the ν_3 band in the IR spectra of magnetite of the Kachkanarsky deposit with increasing internal heterogeneity of the mineral (1 → 2).

The infrared spectra of magnetite also make it possible to determine the contrast of the properties of magnetic separation of a mineral, taking into account the peculiarities of its crystal chemistry. Figure 5 shows the relationship between the position of the ν_3 band and the value of the coercive force (Hc) of specially selected magnetite samples from low-iron ores of the Kovdor deposit. The coercive force is one of the most important magnetic characteristics of the mineral which reflects the rigidity of the ferrimagnetic material, and its anisotropy and defective structure as a result. The value of the coercive force increases sharply with the violation of the uniformity of magnetite [6]. The presence of a clear inverse relationship between ν_3 and Hc of magnetite samples corresponds with these data. We note that the value of the coercive force of the mineral significantly affects the course of magnetic separation. With its increase, flocculation of crushed particles increases with the involvement of non-metallic minerals in the magnetic concentrate [7].

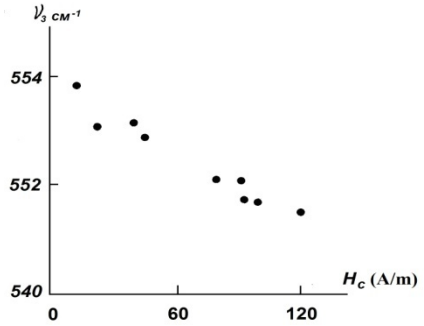

Fig. 5. Dependence of the position of the ν_3 band in the IR spectra on the value of the coercive force Hc of Kovdor magnetite samples.

The most high-temperature iron ore deposits are characterized by heterogeneity of the structure and heterogeneous composition of magnetite. The crystal-chemical features of the mineral are the main geological and mineralogical factor determining the ore dressability. Respectively, it he is reasonable to select technological varieties of ores by using the crystal-chemical features of magnetite. The use of IR spectroscopy here is very effective. It becomes possible to construct geological and technological maps of deposits when mapping the typomorphic feat ures of the infrared absorption spectra of magnetite.

In the infrared spectra of the apatite of the Kovdor deposit, there are two absorption bands that most informatively characterize and objectively fix the crystal chemical heterogeneity of the mineral. They are: a single absorption band in the region of 870–886 cm^{-1}, corresponding to the non-degenerate vibration ν_2 of the anion $(CO_3)^{2-}$, and also part of the asymmetric deformation ν_4 vibrations of the $(PO_4)^{3-}$ ion. There is a clear inverse relationship between the intensity of these bands, which obviously indicates an isomorphic mechanism for the entry of the CO_3 group into the position of the phosphate tetrahedron [7].

The result of this is the established inverse relationship between the intensity of the absorption band of the $(CO_3)^{2-}$ group on the IR spectra of apatite in the region of 870 cm^{-1} and the P_2O_5 content in apatite concentrate (Fig. 6). This is caused by an increase in the structure of the mineral deficit of active Ca_2 ions, which directly interact with the flotation reagent, when phosphorus is replaced by carbon. As a result, the flotation activity of apatite decreases sharply and carbonate material is involved in the concentrate. There is also a decrease in the weight fraction of P_2O_5 in the composition of the mineral.

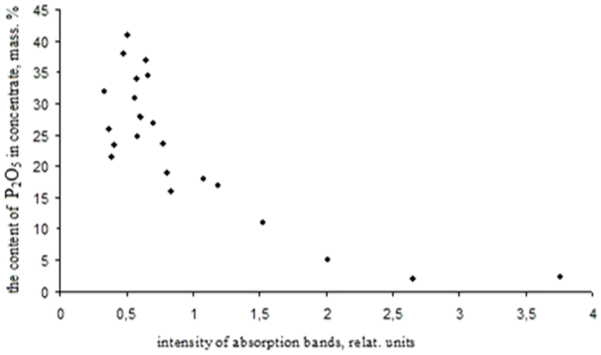

Fig. 6. The relationship between the intensity of the absorption band of the group $(CO_3)^{2-}$ in the IR spectra of apatite of the Kovdor deposit in the region of 870 cm^{-1} and the content of P_2O_5 in the apatite concentrate.

Thus, the IR spectra of the apatite of the Kovdor deposit make it possible to evaluate the contrast of the flotation properties of the mineral in ores of carbonatite complexes, and as a result, to predict the technological properties of ores. The described method for predicting the technological properties of apatite ores of carbonatite complexes is protected by copyright [9].

IR spectroscopy is widely used to study surface phenomena when fixing flotation reagents to minerals [10, 11, 19]. A study of the chemistry of reactions during the adsorption of anionic and cationic collectors makes it possible to conclude the place and nature of the fixation of the reagents, as well as to trace the change in surface properties when exposed to regulators.

4.3 Analysis of changes in the structure and properties of minerals in technological processes

The technological properties acquired by minerals under various influences should be considered as a dynamic process of superposition of constitutional (standard) and secondary (induced) properties [13]. The significant changes in various natural mineral properties (morphology, granulometry, constitution (crystal chemistry), etc.) begin as soon as it undergoes explosion (during mining), crushing, grinding (during processing) and any types of separation. B. I. Pirogov [6] states it is here that the influence of technogenesis due to external energy effects (mechanical, temperature, chemical, etc.) affects the change in the constitution of the mineral. Infrared spectroscopy allows to analyze effectively the dynamics of these changes.

Thus, for example, significant changes are observed in the IR spectra of the initial and ground Pechenga diopside (CaMg (Si_2O_6)). They are related to the appearance of new bands in the samples of the crushed mineral in the region of 3400 and 1640 cm^{-1}, which correspond to vibrations of the OH group. This indicates that during grinding there is a noticeable hydration of the surface of the mineral grains due to the presence of atmospheric one. In addition, the appearance of a double peak in the region of 1500 cm^{-1} is observed. The position of this peak corresponds to the absorption band of the carbonate group and is due to the absorption of carbon dioxide by mechanically chemically activated diopside [13].

The technological cycle of the "life" of the mineral continues after the processing of mineral raw materials. Thus, studies by M. S. Khokhuli with co-authors [13] find that in the IR spectra of the phlogopite of the Kovdor phlogopite-vermiculite deposit, the intensity of bands caused by vibrations of free water molecules and hydroxyl groups (3700 – 1600 cm^{-1}) increases in samples subjected to long-term storage in the underground conditions of the mine (more than 20 years). Consequently, it is proved that the structure of phlogopite changes with the formation of up to 5% vermiculite layers in it during the storage of phlogopite crystals. The changes caused by phlogopites hydration and partial decationation of sections of its crystals ultimately affect the significant deterioration of their technical properties.

The deformations of the minerals structure that occur under the influence of physical influences (temperature, radiation, ultrasound, electro-kinetic, etc.) are the most significant and interesting for technological purposes. Such deformations allow the directional transformation of their technological properties. Infrared spectroscopy provides the choice of the optimal modification method with a targeted change in the contrast of the separated minerals. This allows ultimately optimizing the technological scheme of processing of raw materials.

Figure 7 shows the results of an experiment we conducted when studying the temperature transformations of goethite of the Skelevat iron ore deposit (Kryvyi Rih). We recorded a series of intense absorption bands characterized by the stretching and deformation vibrations of OH groups in the infrared spectrum of goethite in the region of 3600–3200 cm^{-1} at room temperature [14]. It is observed a change in the spectral pattern in this region with a gradual heating of the mineral. To a temperature of 180 °C is a gradual decrease in the intensity of the absorption bands of hydroxyl groups. A sharp decrease in the intensity of this band is observed at 190 °C in the spectrum of the mineral, which again changes into its monotonic decrease at 200°C up to 600°C.

Such a change in the spectrum is associated with a gradual disruption of the FeO – O bond with an increase in temperature to 190 °C and a redistribution of the energies of all the bonds of the system. In the range of 190 – 200 °C, a hematite structure begins to form along with goethite. A further increase in temperature (up to 600°C) leads to the gradual removal of hydroxyl groups and the formation of a stable hematite structure.

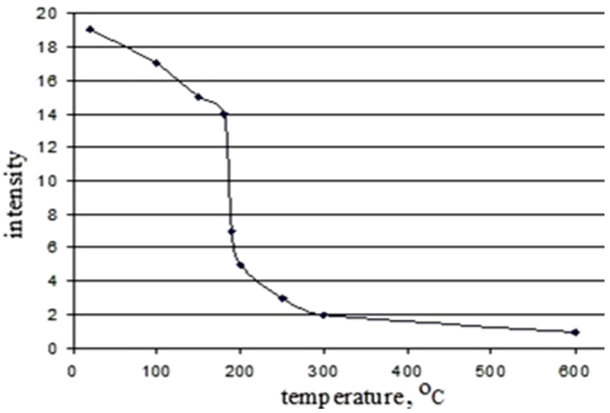

Fig. 7. Changes in the intensity of absorption bands in the region of 3600–3200 cm^{-1} in the IR spectra of goethite of the Skelevat iron ore deposit under temperature exposure.

A group of researchers led by V. Chanturia [16] studied the change in the composition of surface layers and the chemical state of atoms on the surface of galena (PbS) as a result of exposure to high-voltage nanosecond electromagnetic pulses. It was established that after an energetic effect on the mineral, an integrated change in the band area is observed in the range of 1000 – 1400 cm^{-1} of the IR spectrum. This change corresponds to the absorption band of the deformation vibrations of the H – O – H bond, which indicates a change in the hydration of the surface of galena particles. This creates favorable conditions for adsorption of the anion collector and contributes to an increase in the flotation activity of galena.

4.4 Operational analysis of minerals at various stages of technological processing

The effective management of modern mining and processing operations is largely determined by the efficiency and reliability of information on the composition and properties of processed products at various technological cycles. So, much attention is paid today to the development of operational control methods both at the stage of extraction and processing of ores. This is especially true considering the fact that at the end of the 20th century models of portable infrared spectrometers, simple and affordable, with low cost, were developed and are widely available. Consequently, today there are already examples of the effective industrial use of IR analyzers [17, 18].

The IR spectrum of any substance (the position of the absorption bands, their intensity, width and shape) is individual, and can be used to identify this substance. The infrared spectrum of the mineral mixture is the sum of the spectra of the components of the mixture, and the intensity of the absorption bands in the spectrum of each component is proportional to its content in the mixture [15].

Thus, the principle of additivity of IR spectra makes it possible to develop an inexpensive express analysis on the

basis of this method in the cycle of geological and technological control of mining and processing enterprises.

A number of examples of this application of infrared spectroscopy are given in the modern literature [26]. The main focus of these works is the development of methods for increasing the accuracy of analysis. So a group of researchers led by R. A. Skochilova proved that in this case the baseline method traditionally used for the quantitative analysis of minerals by their IR spectra is ineffective [19].

This is due to the fact that the spectra of matrices (batch, core and other products of various cycles of technological conversion) can vary within significant limits, and to a greater or lesser extent overlap the analytical bands of the analyzed mineral. The authors suggest using mathematical-statistical information processing and, in particular, the factor analysis method. This approach allows to find individual spectra and concentrations up to an arbitrary factor from a set of experimental spectra of a mixture with different contents of components. The advantage of this approach is that the IR spectra of several mixtures are analyzed simultaneously in a wide spectral range, and baseline measurements are not required to extract quantitative information.

5 Conclusion

Infrared spectroscopy is a highly effective method for the analysis of minerals, rocks and ores, capable of solving a whole range of problems when choosing innovative solutions for the technological processing of various types of mineral raw materials. The main areas of application of IR spectroscopy are: assessment of grade (quality) of mineral raw materials; analysis of the behavior of minerals in the technological process with prediction of their technological properties; analysis of changes in the structure and properties of minerals in technological processes; operational analysis of mineral substances at various stages of technological processing. The article provides numerous examples of this use of the IR spectroscopy method. The information capabilities of the infrared spectroscopy method are significantly expanded when it is used in combination with other physical and chemical methods of analysis: X-ray diffraction, thermal, electron paramagnetic resonance, scanning microscopy, etc.

The direction of further research is the application of the infrared spectroscopy method in the development of new technologies for the extraction of useful components based on nanotechnologies.

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The use of new structural solutions of retaining walls to ensure the stable operation of the "base – engineering structure" system

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Abstract. During the design and operation practice, it is necessary to assess the possibility of deformation of structures located on foundations which are able to precipitate and subside. Only with reliable and accurate determination of the stress-strain state of structures of structures together with soil masses during modeling, it is possible to apply the finite element method in practice. The calculations using the PLAXIS and LIRA programs made it easier to analyze the stress-strain state of the soil mass and the stability of retaining walls: I option is corner retaining wall; II option is retaining wall with a structural surface. With the same soil base (layer geometry and physicomechanical properties), loads and boundary load conditions, it is obvious that for the II option the entire mass of soil is included in the work and the stresses are uniformly distributed over the front and foundation plates (over common stresses), uniform structural deformations are observed and soil base, which, in turn, ensures the stability of the retaining wall (according to the general picture of movements) The validity of the theoretical forecast of the behavior of engineering structures interacting with an unevenly deformed base cannot be obtained on the basis of the regulatory framework. This gap can be filled in when modeling the "base – engineering structure" system using modern calculation programs using the finite element method.

1 The problem and its relationship with scientific and practical tasks

Retaining walls are now widely used not only in civil and industrial construction, but also in urban planning for complex landscapes.

There are situations of construction of objects in cramped conditions, in adverse territories with active acting deformation influences, which makes the use of existing types of retaining wall structures more complicated. An important factor in solving the emerging problems is the high level of expertise on engineering and geological conditions in large industrial cities, especially in regional centers. Modern research is mainly focused on clarifying the geotechnical nature [1].

As earlier experience shows, the development of hazardous processes in urban areas continues. First of all, these are the processes of flooding in the territories, the development of landslide deformations, subsidence of the surface above mine workings, subsidence of loess soils, etc. These processes are associated with a decrease in serviceability or deformation and the destruction of buildings and structures.

According to expert estimates, 90% of the territory of Ukraine is characterized by complex engineering and geological conditions, worsening due to the influence of natural and technogenic factors.

As for the Kryvyi Rih city, the technogenic load on the geological environment is several orders of magnitude higher than for other adjacent cities. It should be especially noted that iron ore has been mined for about 200 years, up to 47% of the built-up territory is located in the developed space. In modern practice, the construction of facilities in cramped conditions, in areas subject to adverse physical and geological processes, complicates the use of existing types of retaining wall structures. Extremely unfavorable combinations of underworking with subsidence of soils, with flooding, etc. are encountered, therefore, in order to protect the settlements, industrial facilities, utilities and transport communications with a certain level of safety, it is necessary to use engineering structures of a special type that would perceive the influence of variables of engineering -geological, natural and technogenic factors.

Building on a deformable foundation is very widespread. In recent years, as the territories that are most favourable for development have been exhausted, construction in territories with difficult conditions, which are characterized by significant uneven deformability of the base, has become increasingly widespread [2, 3].

Engineering methods of calculation, which are traditionally used in design, cannot answer all questions

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of operational practice. Widespread in many countries are programs based on the finite element method (FEM). These programs have a fairly wide scope and according to them it is possible to determine the stress-strain state, including structures, in the "base – engineering structure" system [4-7].

2 Analysis of research and publications

Complicated engineering and geological conditions - this is a geological environment that includes specific soils, hazardous natural or technogenic processes, geomorphological conditions, geological and hydrogeological factors of interaction with buildings and structures, belong to the II and III category of complexity of engineering and geological conditions [8, 9]. Many scientists have devoted their work to determining the lateral pressure of soil on retaining walls, taking into account their joint work with the soil mass.

So, V. Raiuk [10, 11] investigated the nature and magnitude of the lateral pressure on the vertical face of the retaining wall, taking into account its deformation and displacement, using the model of linearly deformable half-space, but he did not consider the joint work of the vertical wall and the foundation as a single system that interacts with soil. K. Chernyshova [12] investigated the effect of the flexibility of a vertical wall on the lateral pressure of the soil.

Y. Luchkovskyi [13], using the superposition method, provides a solution for determining the lateral pressure of soil on retaining walls from narrow loads and concentrated force. He draws attention to the attenuation with a deepening of lateral soil pressure from the load. However, these authors, when determining the lateral pressure, did not take into account the joint work of the vertical wall and the foundation as a single system that interacts with the base.

Y. Symvulydy [14] calculates a flexible retaining wall taking into account the interaction of all its elements with the base, but introduces a linearly deformable half-plane as a model of the natural base, which is not entirely correct. In addition, this method does not allow taking into account the influence of the loading on the stress-strain state of the system.

A significant amount of research has been devoted to the static calculation of retaining walls [15, 16]. The number of works on the dynamics of these structures, especially taking into account the elastic properties of their materials, is much smaller [17, 18]. Usually, dynamic calculations are performed if pulsed, vibrational or moving loads act on the structure [19].

3 Formulation of the problem

When constructing retaining walls in complex engineering and geological conditions, it is necessary to achieve:
– increasing the stability and strength of retaining walls;
– reducing the cost of used building materials;
– decreasing in the volume of earthwork; reduction of strain unevenness;
– reduction of construction time;
– improving the conditions of filling and compaction of the filling;
– increasing operational reliability, quality of work and increase the service life of retaining walls.

Thus, to assess the stress-strain state of retaining walls, it is necessary to take into account the joint work of the entire wall with soil and the use of more reasonable soil models in the region of its vertical and horizontal elements.

The aim of the research is to study the stress-strain state of the base and retaining wall with a structural surface (PSSP) taking into account their contact interaction to increase the stable operation of the "base – engineering structure" system.

4 Statement of material and results

The most common engineering structures in urban design today are retaining walls that are used for fencing:
– slopes of embankments and excavations within the area and access railways and roads in case of inability of carrying out slopes with the necessary inclination;
– pits during the construction process when it is impossible to perform slopes with the necessary inclination;
– special structures – ramps, bulk materials warehouses, bunker overpasses and ore yards of metallurgical plants;
– individual overpriced or underpriced sections of technology located within and outside buildings according to technology conditions.

Since ancient times, massive retaining walls of stone blocks and slabs have been used to support slopes, excavations, embankments and natural slopes. Technical progress and the laws of economic efficiency draw attention to the design features of the retaining wall and the characteristics of the interaction of the foundation with it. Important issues are optimizing the design of retaining walls, taking into account the following characteristics:
– the maximum inclusion in the work of soil filling;
– decreasing the values of the active soil pressure;
– increasing resistance of the displacement along the sole of the retaining wall;
– minimization of material consumption.

An important factor in solving the tasks is a high level of knowledge of engineering and geological conditions in large industrial cities and regional centers. Modern research is aimed at clarifying mainly geotechnical nature. The experience of recent years shows that the development of hazardous processes in urban areas continues. First of all, these are the processes of flooding of territories, the development of shear deformations, subsidence of the surface above mine workings, subsidence of loess soils, etc. These processes are associated with a decrease in serviceability or deformation, destruction of buildings and structures [2].

It is not always possible to use well-known technical solutions in the undermined territories and subsiding soils with complex deformations of the base, since they are not suitable for these working conditions. The existing structures of retaining walls are not designed for

additional efforts from horizontal displacement or vertical movement of the soil, which causes stress concentration in the lower part of the front plate and, of course, will lead to the destruction of the structure.

Therefore, there was a need for the use of new designs that would take into account these shortcomings and increase the reliability of operation of unsuitable territories.

A retaining wall is proposed, which can be used to stabilize unstable slopes and gradients, as well as in undermined areas with horizontal and vertical movement of soil (Fig. 1–4) [20].

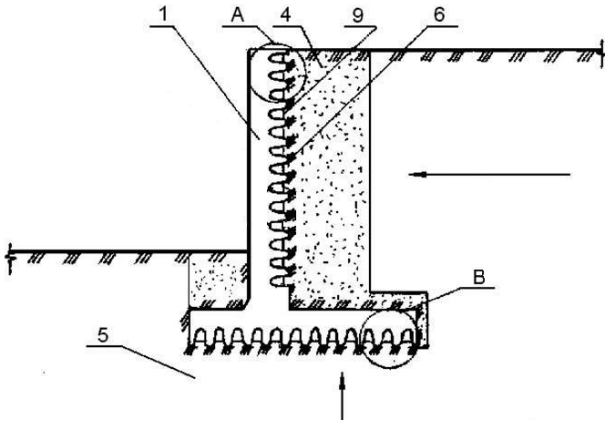

Fig. 1. Structural retaining wall.

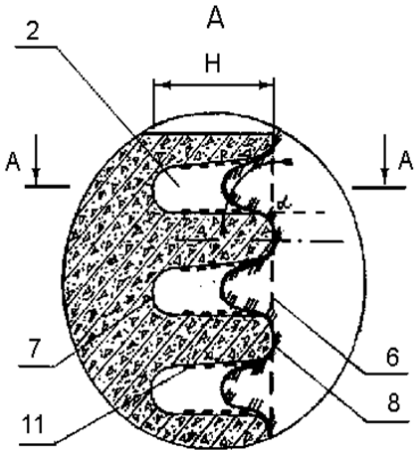

Fig. 2. Node A.

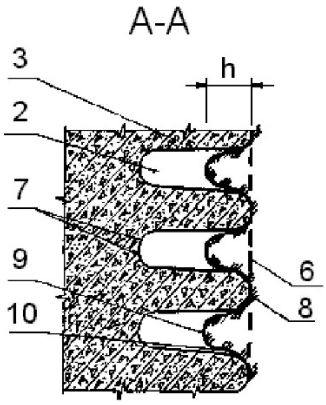

Fig. 3. Section A-A.

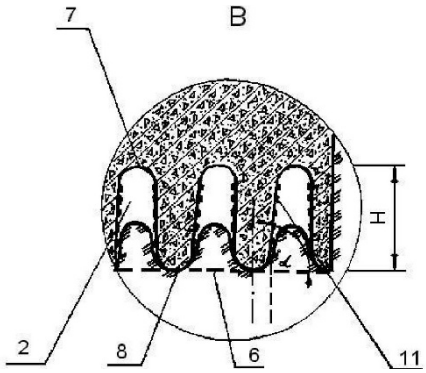

Fig. 4. Node B.

The new design of the retaining wall with a structural surface can be used to protect the territory from collapse. It represents an improvement of the monolithic retaining wall of the corner type by forming contact surfaces with cavities on the vertical and foundation elements from the ground, which allows to reduce the peaks of contact stresses on the surface of the vertical element of the retaining wall due to the uniform redistribution of pressure in the approaching soil, to increase the shear resistance along the sole retaining wall, in addition, in the case of additional uneven deformations of the base acting on the foundation the element, to improve its operation, which allows a retaining wall to perceive and evenly redistribute the efforts of complex loadings.

The monolithic retaining wall of the corner type includes vertical and foundation elements, and on the surface of the vertical and foundation elements, alternating support parts and cavities are placed on the contact side, while the cavities are made in the form of truncated pyramids of the same size and directed by a smaller base into the vertical element, while the volume cavities is determined by the formula:

$$V = \frac{2 \cdot \omega_{\phi} \cdot N \cdot H \cdot (K \cdot (\delta + h) - h)}{n \cdot R \cdot (H - \delta - h) \cdot [1 + (\cos \alpha + f \sin \alpha)]}, \qquad (1)$$

where: V is the volume of cavities; N is the external normal load relative to the envelope surfaces of the supporting parts, which acts horizontally; R is the ultimate bearing capacity of the soil at which the static equilibrium of the retaining wall is established and maintained; H is total depth of the cavities; h – is the depth of penetration of the soil into the cavity; δ – is the absolute value of the forced displacement of the soil at the considered point; S – is the actual contact area of the supporting prismatic sections; K – is the safety factor for the contact area, which takes into account possible changes in the estimated power loads; f – is the coefficient of friction between the soil and the supporting prismatic sections; ω_{ϕ} – is the generalized coefficient for taking into account the shape of the volume of prismatic sections and their projection area along the envelope surfaces of the supporting parts; n – is the coefficient of conversion of contact pressures into their projection on the normal axis to the envelope surface of the supporting parts; α – is the angle formed by the envelope of the plane of the supporting parts and the tangent plane, which is drawn to the surface of the prismatic sections at a height h.

For a smooth perception of deforming actions from moving soil to a vertical element and deforming actions from vertical movement of soil to a foundation element, lateral faces of the planes are rounded. To reduce the effective friction forces on the vertical element, lateral faces of the planes are coated with an antifriction layer. To compact the backfill soil and to prevent the penetration of soil into the cavity, a sheet of resilient material is placed on the contour surfaces of the supporting parts.

The proposed retaining wall 1 consists of a vertical element, which has cavities 2 and supporting parts 3, in the direction of action of the shifting soil, and a foundation element, which has cavities 2 and supporting parts 3, in the direction of action of the vertically moving soil.

The backfill soil 4 and the base soil 5 are directed into cavities 2, which have the shape of truncated pyramids, with bases 6 and side faces 7. Side faces 7 and cavities 2 constitute the actual side surfaces of the support parts 3.

Facets 7 form ribs 8 in the plane of the bases 6, which make up the envelope surface of the supporting parts 3 (Fig. 5–8).

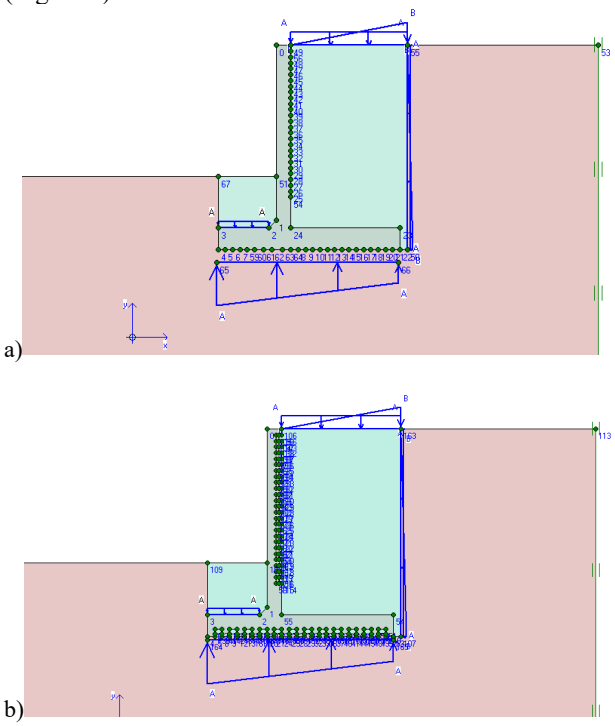

Fig. 5. Design schemes: a) I option; b) II option.

On the enveloped vertical surfaces of the supporting parts, between the soil and the cavities, depending on the type of soil conditions and the nature of the deformations, a sheet of resilient material 9 can be placed.

The soil directed into the cavity is in contact with the side surfaces of the supporting parts 3 by the supporting prismatic sections 10 of the side faces 7 of the cavities 2. An antifriction layer 11 can be made on the surface of the supporting parts, which is placed on the surface of the retaining wall.

With the development of the deforming load, that is, with vertical and horizontal movement of the soil relative to the retaining wall 1, after its installation, the soil penetrates into the cavity.

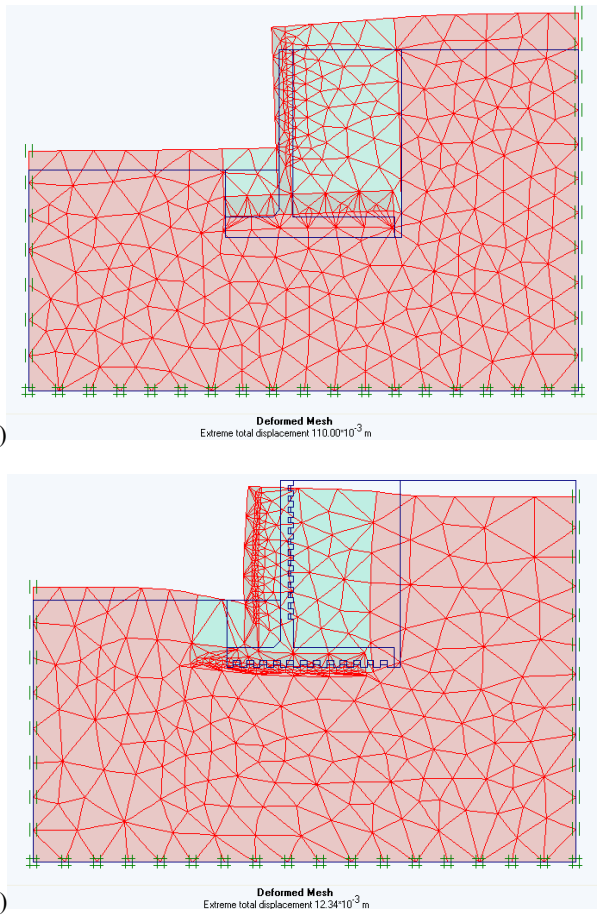

Fig. 6. Deformation of the mesh of finite elements: a) I option; b) II option.

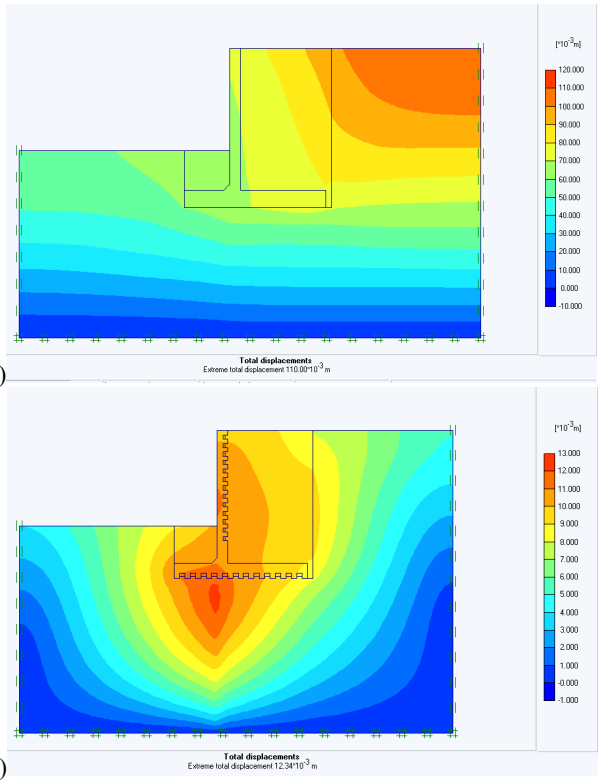

Fig. 7. Complete movements: a) I option; b) II option.

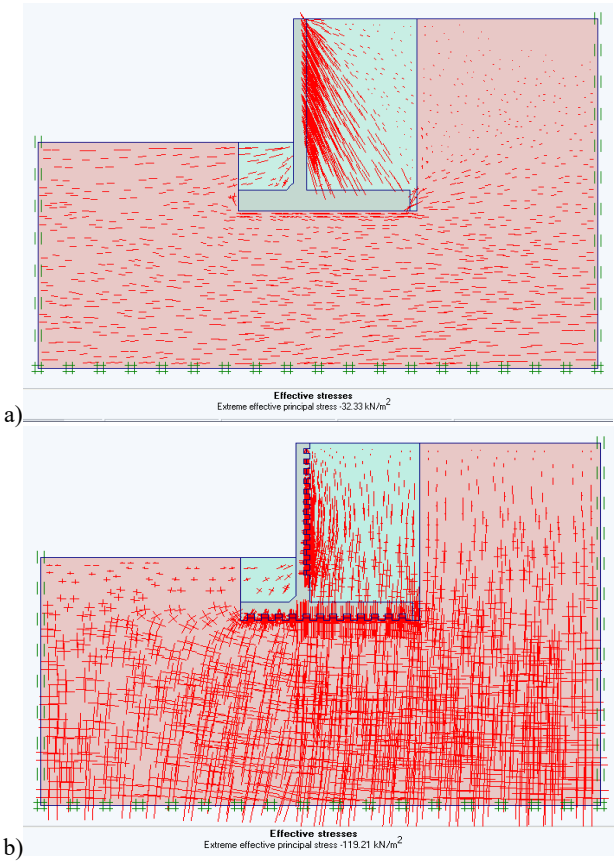

Fig. 8. Effective stress σ_{ef}: a) I option; b) II option.

Regarding the vertically built enveloping planes of the supporting parts 3, the vertical and foundation elements of the retaining wall 1, the acting loads in ordinary geotechnical conditions are the active lateral pressure of the soil 4 backfill and the pressure from the dead weight of the retaining wall 1.

The retaining wall is in stable equilibrium position, and the plane of the supporting prismatic sections 10 are proportional in depth to the ordinates of the lateral pressure and the weight of the retaining wall 1, with the such limiting soil resistance under which it is held in statically balanced position.

Under the conditions of detection the actions of forced horizontal and vertical displacements of the soil, normal loads along the front of movement of the soil are transformed into frontal passive pressure, and in the direction of movement they cause lateral friction, and in all cases they are applied to individual supporting parts 3 at an angle and much larger than the usual active soil pressure.

In this case, an increase in contact pressure at the prismatic support sections 10 above the limiting values in statics is impossible and also leads to the fact that the soils 4, 5 which are imposed on the contact are plastically destroyed and freely move in the cavity 2 until deformation effects are manifested.

The shape of the cavities 2 (truncated pyramid) is most efficient for soil compaction. Soil, falling into the cavity in the region of the lower base of the pyramid and passing the path to its upper base, spontaneously compact.

After that, the contact pressure decreases to the initial level, that is, the actual external surface of the retaining wall 1 caused the structure to work with constant resistance to shear forces, impending unstable slopes and slopes, as well as in undermined areas with horizontal and vertical movement of soil.

The current level of computers and software allows for accurate calculations of the stress state of fairly complex systems.

The use of modern programs oriented to the calculation of systems with a large number of unknowns is more efficient than calculations using traditional schemes.

According to some programs, it is possible to solve not only linear but also nonlinear problems.

In this case, consideration is given to the characteristics of the deformation of various materials: reinforced concrete, steel, base, etc.

To account for the work of the soil, several models have been developed that take into account the transition of the soil to a plastic state, viscoelastic deformation, and other models.

For each soil condition and type of stress state, it is advisable to select certain deformation models.

Of particular interest is the PLAXIS program for modelling contact interaction of elements of the “base – engineering structure” system [21, 22].

The PLAXIS program is a finite element package designed specifically for the analysis of the deformation and stability of geotechnical structures.

Modelling using the PLAXIS program made it possible to analyse the stress-strain state of retaining walls interacting with the soil mass in accordance with the design schemes for two options (Fig. 5): option I – corner retaining wall; II option – retaining wall with a structural surface. The simulation results are shown in Fig. 6–8.

As a result, a significantly smaller displacement in the retaining wall with a structural surface U_{cm}=12.34×10^{-3} m was obtained, but the entire soil mass with a more uniform distribution and reduced values was included on the contact surface σ_{ef}.

In order to determine the forces in the front and foundation plates, two variants of retaining walls were simulated using the “LIRA” program [23]. The design schemes are presented in Fig. 9. The calculations used the Mohr-Coulomb model.

Engineering-geological conditions and design loads are similar to previously performed calculations.

The first stage of the calculation was performed with a surface load q = 49 kN/m^2. The second stage of the calculation – with an additional vertical component for the front plate from the horizontal movement of the soil q = 21 kN/m^2.

The obtained values of bending moments in the front and foundation plates for two loads are presented in Fig. 10–12.

A new retaining wall structure with a structural surface was designed to secure the slopes of the Sushkov beam, the area of which is about 2 hectares (Fig. 13, 14).

The beam is located in the central old part of the city of Kryvyi Rih and was formed as a result of iron ore mining.

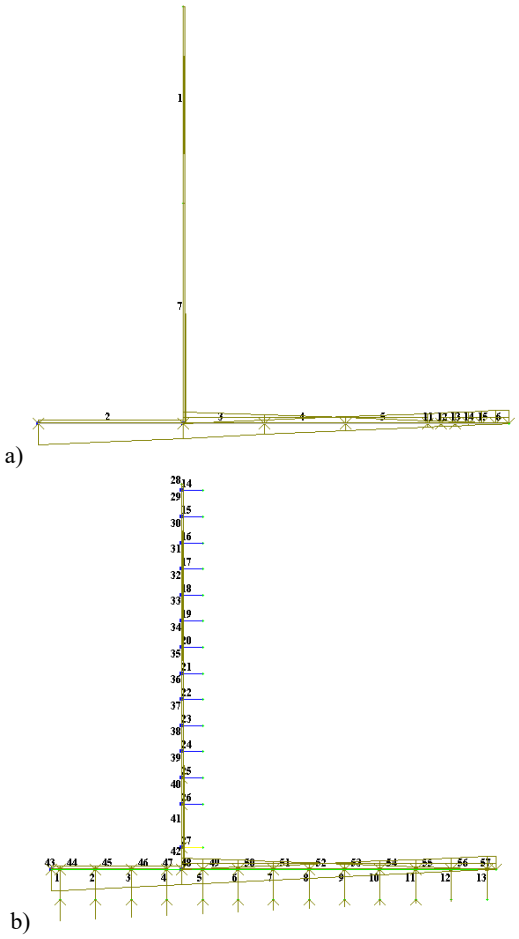

Fig. 9. Settlement schemes: a) I option; b) II option.

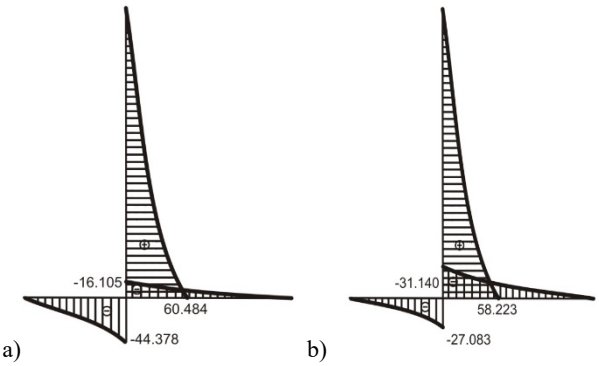

Fig. 10. Diagrams of bending moments: a) I option (first stage); b) II option (first stage).

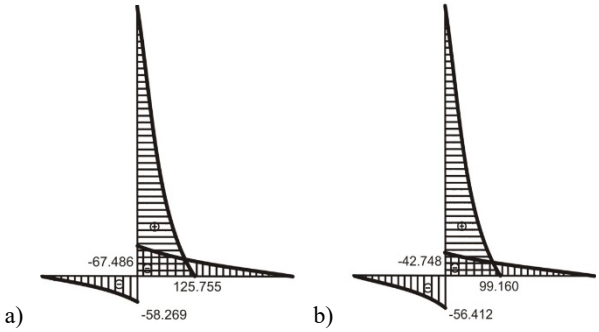

Fig. 11. Diagrams of bending moments: a) I option (second stage); b) II option (second stage).

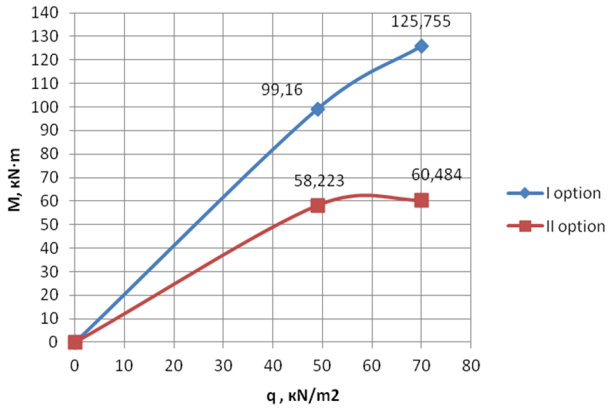

Fig. 12. Dependence of moments on surface load.

Over the past five years, engineering and geological conditions have worsened in the area of the beam: slope shifts in some places up to 12 cm, collapse of some slopes were observed, which in turn affected the normal operation of five-story residential buildings located at a distance of 8 m from the northern border of the beam.

The beam itself has slopes of 5 to 54% and is a dumping site for household waste.

In the geological structure of the site there are loams of the Quaternary sediment, clays, limestones under which the Precambrian clay shales are underlain. Groundwater is at a depth below 21 m.

The rational use of the territory was made possible only through the use of retaining walls with a structural surface.

They were installed around the perimeter of the site and diaphragm along the tiers.

The volumetric work of the retaining walls like the "egg's volume" made it possible to include the entire soil mass around the beam, redistributing the contact forces in the best way, thereby reducing the maximum effective loads from the base.

A compact planning solution allowed in the extreme opposite points of the beam, where the greatest depth is located – 7.5 m ÷ 8 m (section 2-2, 7-7) place underground parking garages for 100 cars each. At the same time retaining walls simultaneously serve as walls of garages.

Above the underground garage are sports grounds for various sports with a modern bulk coating.

As mentioned above, the slopes of the beam are reinforced with monolithic reinforced concrete retaining walls, the height of which varies from 0.5 m to 3 m (section 1-1, 3-3, 4-4, 5-5, 6-6) depending on the existing depth beams, as well as their tiered device.

The rest of the territory is designed: a quiet recreation area, a children's zone, a decorative zone, a walk-through zone, a public garden area.

5 Conclusions

The validity of the theoretical prediction of the engineering structures' behavior interacting with unevenly deformed foundations cannot be obtained on the basis of the regulatory framework. This gap can be filled in when modeling the "base – engineering structure"

system using modern calculation programs using the finite element method.

The calculation results were confirmed by experimental studies conducted previously. Mathematical modeling made it possible to clearly demonstrate the decrease strain on the contact surface and in the body of the retaining wall with a structural surface with additional forces of soil displacement. The phased filling of voids leads to a uniform distribution of deformations, in the long run increases the life of the structure, thereby ensuring an economic effect. The design feature of the retaining wall with the structural surface during soil interaction with it increases the bearing capacity of the base due to the joint work of the retaining wall structure and the deformable base.

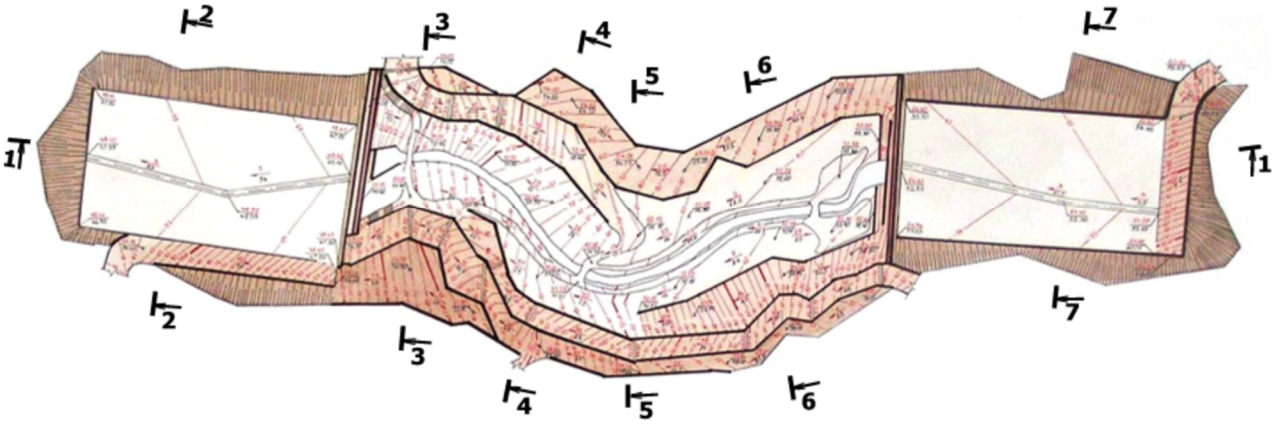

Fig. 13. The plan of the retaining walls with a structural surface in the Sushkov beam.

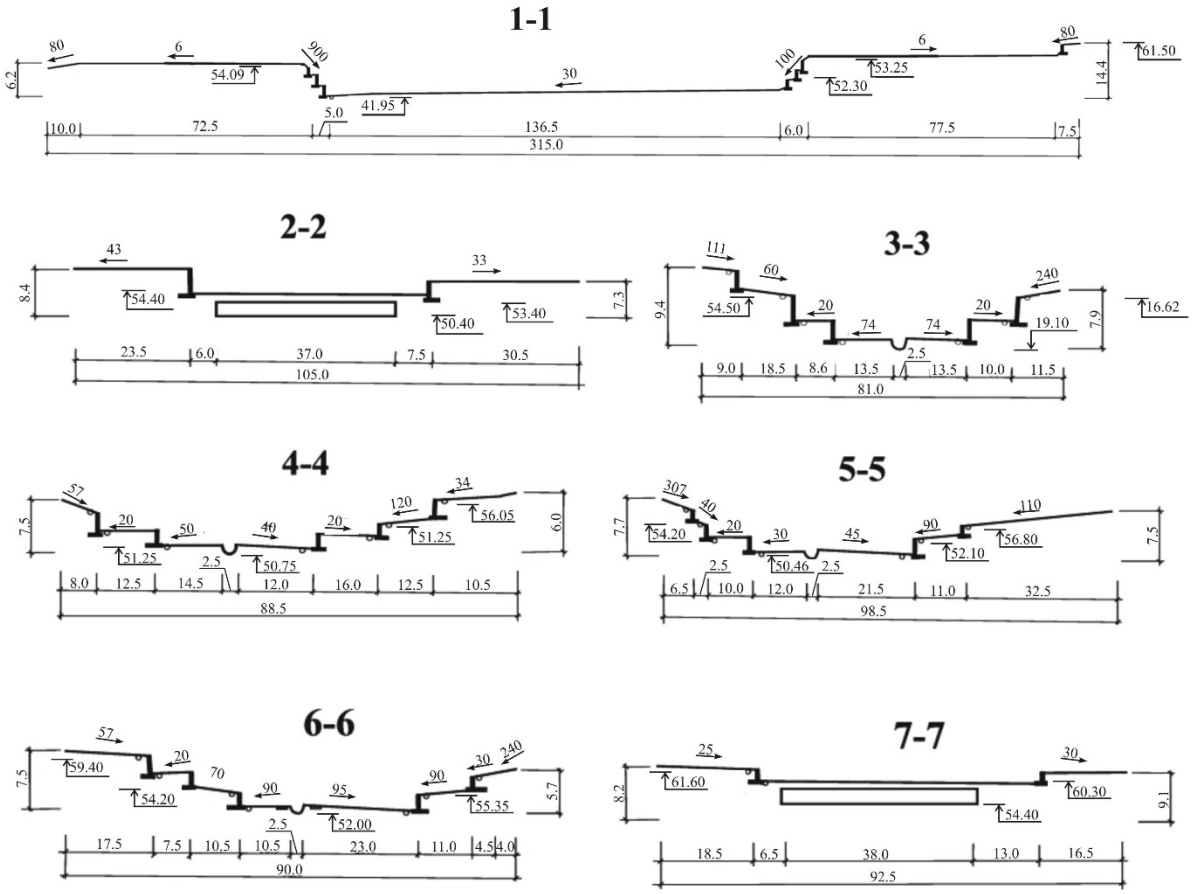

Fig. 14. Sections 1-1, 2-2, 3-3, 4-4, 5-5, 6-6, 7-7 along the Sushkov beam.

The proposed retaining wall can be used to stabilize unstable slopes and inclinations, as well as undermined territories of I, II, III, IV groups and subsidence soils.

The proposed retaining wall is characterized by high reliability of operation in a critical situation of unforeseen emergency increase in horizontal and vertical power load. This is explained by the work of the structure itself, that is, with increasing load, the supporting areas of the prismatic sections increase all the time, and since the cavity volume sooner or later will be completely filled

with soil, then the supporting area of the retaining wall will increase significantly, and the average pressure will decrease when achieved degree of compaction. However, after this, the retaining wall will not be able to work in the mode of redistribution of contact pressures.

With possible vertical displacements of the soil, a constructive solution is also used that allows taking this type of deformation effects into account.

The use of previously unsuitable territory was made possible because of using retaining wall with a structural surface, which made it possible to obtain a significant economic effect due to a new design solution.

The use of this design for securing landslide slopes is advisable when erecting a height of up to 3 m, and the best work is achieved with a perimeter device.

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Determination of the transfer step of the ore chute while mining the technogenic deposit of the bulk type

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Abstract. Further development of the open mining works on the domestic enterprises will be accompanied by the worsening of mining-geological conditions and declining of the quality of iron ore raw materials. In the same time, the accumulated mining wastes, that can make the technogenic deposits, pass into one of the important sources of the mineral raw materials. Taking into account this thing, the development and implementation of the modern technological circuits of the technogenic deposit development is an actual calling for mining industry, and determination and optimization of process conditions of the technogenic deposit development – is the scientific task of this publication. The obtained results of studies of the optimum step value of the ore chute transfer during the technogenic deposit development can be used by design organizations and mining enterprises for designing works. The obtained methodology and the proposed mathematical dependencies will reduce the cost of mining of the technogenic deposit due to the reasonable timely transfer of the open ore chute.

1 Introduction

As a result of activities of the mining and processing industry of the Kryvyi Rih region, hundreds of millions of cubic meters of production waste are accumulated on the surface in the form of overburden, sludge, slag, ash and so on, that increase the environmental load. More than 2 billion tons of rock mass is extracted annually from the Ukrainian subsoil, 60-70% of which is stored in the dumps. However, the level of utilization of production waste reaches only 12-15%, while in the advanced countries of the world it reaches 80%. The tendency for the use of secondary resources is observed in the USA, Japan, Canada, Great Britain, France, Germany, Republic of South Africa and other industrialized countries [1-4].

According to various estimates, up to 13 billion tons of overburden and up to 6 billion tons of washery refuses of low-grade iron ores are contained in the dumps and tailings ponds of Kryvyi Rih mining and processing enterprises. At the same time annual economic damage from environmental pollution is estimated at $300 million. However, the prospects for the development of mining are characterized by an increase of the mineral output with a constant decrease in their quality and complication of the conditions of exploitation of natural deposits. In future, deposits of low quality ores, comparable to the ores of technogenic deposits, will be involved in the development.

The amount of mineral resources contained in mining waste is anthropogenic raw material, the involvement of which in the processing will reduce the cost of exploration for new and mining of exploited deposits, release land occupied waste and their reclamation, elimination of sources of pollution from the surrounding environment around operating enterprises [5].

Thus, anthropogenic formations formed by the storage of mining and processing waste, provided the required quantity and quality of mineral raw materials, can be suitable for industrial use and as a result can be considered as technogenic deposits.

By definition of V. O. Gneushev [6], man-made mineral deposits are places of accumulation of mineral extraction and processing of mineral resources whose reserves are estimated and have industrial significance. Like natural mineral deposits, such deposits have a certain structure spreading of useful components, the zone of secondary enrichment and oxidation.

It is established that the deposits that are mined in 40th – 50th of 20 century, accumulated a significant amount of technogenic waste with relatively high content of useful components, because at that time the extraction and processing conditions were much higher than today [7].

Dumps of Kryviy Rih mining enterprises are made up of overburden rocks that have been removed from the subsoil, moved and stacked. Their mineral and chemical composition, texture, structure, physical, technological, technical and other characteristics have practically not changed in comparison with the corresponding parameters of these rocks in the geogenic deposit.

Thus, the accumulated mining waste, which may be technogenic deposits, will eventually become one of the important sources of mineral resources. In view of this,

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the problem of development and improvement of formation and mining technologies of technogenic deposit with optimal parameters that would ensure maximum efficiency of its development is especially up-to-date and needs further research.

2 Materials and methods

V. D. Evtekhov [8] claims that the technogenic deposits represented by the waste heaps of mining enterprises have been studied more deeply to date, and the first steps have been taken in the direction of their industrial exploitation. For some rocks extracted from the depths along with iron ores, and for some areas of their application, the problem of recycling can be considered theoretically and practically solved.

For example, the production of rubble stone, ballast raw materials, as well as materials for road construction of granitoids, substandard magnetite-silicate quartzites and different composition of shale.

Undoubtedly, the development of bulk man-made deposits would be economically feasible. This is due to the fact that the cost of finished products from man-made raw materials is lower than the primary cost of raw materials extracted from the subsoil.

In addition, the terms of development of technogenic deposits from exploration to production of the finished product is much less than in geogenic one.

In order to bring the technogenic deposit into operation, it is necessary to solve a complex problem, which includes a number of issues, such as determining the mineralogical composition of the technogenic deposit, its area and capacity, the content of the useful component, the particle size spreading; identifying the most promising areas; collecting data on the spatial spreading of pollution in man-made sediments; estimated calculation of inventories of useful components, as well as a plan of development taking into account technological types of shifts and compilation of geological map and sections [9]. However, the haphazard storage of rocks in the dumps leads to complications in their development as man-made deposits, which is explained by the higher costs of performing the required amount of mining work on the extraction of mineral resources.

V. V. Kustov proposes [10] to use the phenomenon of segregation, which is the process of separation of bulk material by size as a result of interaction between particles of bulk material and additional external factors, to predict the parameters and qualitative assessment of the massif of rocks of technogenic deposits. The author notes that the effect of segregation is occurs in the dumping of waste rocks, and therefore it is important to know the regularities of segregation processes in determining technological schemes of repeated impact on the dumps, in solving problems of engaging in the production of technogenic deposits with certain zones of concentration of useful component of the bulk and prediction of objects. Therefore, according to the author, one of the main criteria when choosing a rational technology for the formation of anthropogenic deposit is the degree of segregation of bulk rock, which will allow to form an technogenic deposit with the necessary parameters that would provide a given quality of mineral raw materials.

On this basis, Kustov developed 11 technological schemes for the use of dump equipment for the formation of technogenic deposits of layered structure, which would provide the maximum degree of segregation of bulk rocks with the purpose of maximum material disclosure in size.

The developed technological schemes involve the use of conveyor or wheel transport and are distinguished by the technological operations performed. The most effective technological schemes in terms of qualitative separation of loose rocks into fractions are schemes with conveyor dumping and in the case of dump trucks for peripheral dumping.

The group of scientists of IGTM NAS of Ukraine under the leadership of M. S. Chetverik productively explored the problem of the technology of technogenic deposits' development [11], but mainly deposition of shore type, that significantly narrows the scope of the results.

A team of scientists from Kazakhstan led by Ye. I. Rogov investigates the development of technogenic deposits of bulk type, but with the use of leaching [12]. However, this technology cannot be effectively applied for the Kryvyi Rih iron-ore deposits. In addition, its application will increase the environmental load to the region.

Well known the schemes of selective storage of rocks in waste dumps: storage of each separate type of raw material on its own, separated in parts of surface area; storing different types of raw materials in one plot with their distribution in plan; storage of different types of raw materials in one section with their height distribution; storage by a combination of the second and third methods. Storage by the first method is in fact a common dumping. Selective storage with height distribution of raw materials is possible when the prospective value of the ores is clearly defined. At the same time, the least valuable ores should be at the base of the rock mass and deep into its side parts, and the most valuable ones should be at the upper tiers of the technogenic deposit. The most valuable fraction will be concentrating on the outer sides of the rock mass, so its subsequent shipment will not cause any inconvenience. However, over time, the importance of certain types of minerals may change, so the current storage system in the future may interfere with access to the mineral component.

In this way, the most selective warehousing technologies provide for the opening of a deposit only after its backfilling by passing the surface trenches [13-15]. Technology for the formation of technogenic deposits with the establishment of tunnels system and ore pass, described in the investigation [16] has fundamentally difference from the described ones.

This technology involves the discovery of a bulk technogenic deposit as an object of development, still in the formation stage. The developed technology allows to reduce the costs for development of the technogenic

deposit and to increase the completeness of the mineral's extraction by simplifying the access of extractive equipment to the mineral. Despite this, this technology has several disadvantages:
- the formation and processing of technogenic deposits in this way involves significant capital expenditures during the building phase. At the same time, 17% of them are the cost of laying the fastening system, which is explained by the complexity of the installation work and the high cost of the used materials;
- fastening system that is in the thickness of the technogenic field, especially horizontal tunnels, require periodic metrological control, because they are in a constantly tense state;
- the installation of the vertical fastening system requires only a bulldozer peripheral method of dumping. It is characterized by an almost uniform distribution of oversize over the thickness of the technogenic deposit;
- in this technological scheme with the placement of vibratory feeders at the bottom of the vertical cavities, is possible emergency stop of work due to oversize of rock. Therefore, the proposed technological scheme requires a uniform particle size distribution without oversize.

The technology of the technogenic deposit development with open ore chutes is free of the above mentioned disadvantages. In this case the formation of the technogenic deposit is performed by known storage technologies, and after the backfilling of the technogenic deposit or if a certain slope enters on the designed contour, a mobile or stationary ore chute in the form of an open trench can be formed on it. A transfer bin equipped with a vibrating feeder is placed at the bottom of the ore chute. The method of the technogenic deposit development is as follows: the wheel loader removes the minerals from the face and transports it to the accumulating tank, from where it is delivered over the open ore chute to the vibrating feeder under the action of gravitational forces and transferred to the means of railway transport. Choosing the location of the technological complex we should take into account the effective distance of transportation of the wheel loader, that is limited to 500 m. However, this publication does not consider the choice of the direction of development of mining works from the receiving tank of the vibrating feeder, the optimal values of the width of the work stope and other parameters of the elements of the development system.

At the same time, the development of the technogenic deposits of the bulk type according to this technology is an imperfect and is characterized by low technical, economic and technological indicators, which keep its further introduction. This situation can be corrected by identifying and optimizing the parameters of the elements of the technogenic deposit development system, as well as further improving existing technologies by increasing the efficiency of equipment use.

3 Results and discussion

For a detailed study and further research of the technological scheme was first investigated range of pneumatic wheel loaders. It was considered five pneumatic wheel loaders on the example of the model range of the "Caterpillar" company. First of all, the technical parameters of the CAT-962L, CAT-966L, CAT-980H, CAT-992K, CAT-993K machines were analyzed [17], and then their productivities were calculated for the conditions of technogenic deposits.

For these conditions capital and operating expense for mining of technogenic deposit with each loader were calculated. For the accuracy of the results, calculations were made for transport distances of 100 m, 200 m, 300 m, 400 m and 500 m. The results of these calculations of capital and operating expense per 1 m^3 of the rock are shown in table 1.

Table 1. Calculation of total CAPEX and OPEX for the different pneumatic wheel loader, USD per 1 m^3

L, м \ E,m^3	4,4	7,4	8,2	12,3	23,7
100	0,07	0,05	0,06	0,25	0,21
200	0,11	0,09	0,11	0,48	0,34
300	0,11	0,09	0,11	0,48	0,34
400	0,23	0,17	0,21	0,86	0,71
500	0,29	0,21	0,28	1,15	0,86

Consideration of the proposed examples of equipment from the point of view of economic feasibility, performance or combination of these components will indicate the absolute inappropriateness of the application of the CAT-992K brand with a bucket volume of 12,3 m^3, since this sample cannot compete with any of the presented models, having high specific indicators costs at relatively low productivity.

The results obtained allow us to conclude on the economic feasibility of using pneumatic wheel loaders CAT-962L, CAT-966L, CAT-980H for mining of technogenic deposits with open ore chute. The results are shown in fig. 1.

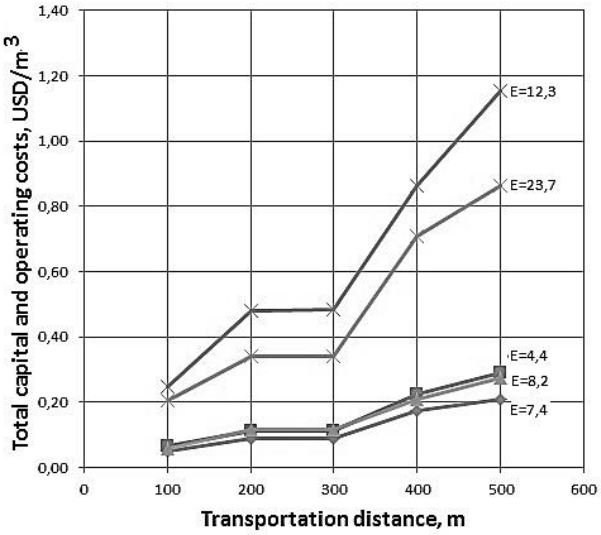

Fig. 1. Dynamics of mining costs for loaders with different buckets (*E*) depending on the distance of transportation.

But for the further research we will select loader

CAT-966L, which has the best technical and economic indicators.

Obviously, in order to maximize the productivity of the loader, which operates according to the technological scheme with open ore chute, the distance of transportation of technogenic raw materials should be minimal. Such condition will be fulfilled, developing the massif by radial slicing, as shown in fig. 2. The essence of technology is as follows.

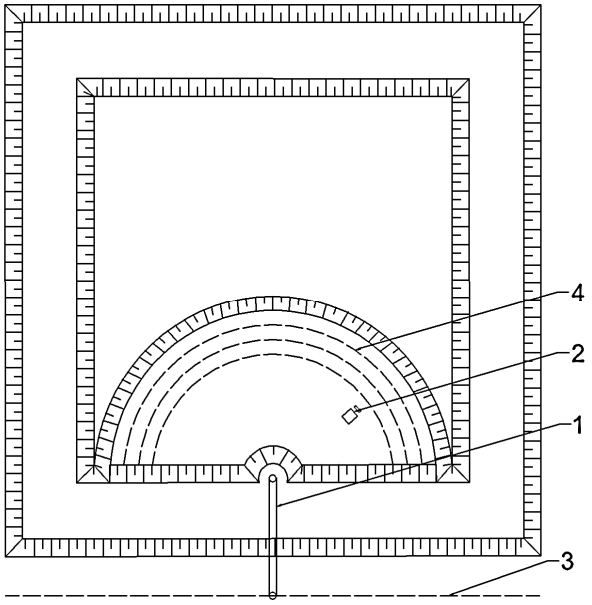

Fig. 2. Scheme of development of the technogenic deposit by radial slicing with pneumatic wheel loader: 1 – open ore chute; 2 – pneumatic wheel loader; 3 – axis of a railway transport; 4 – radial slicing.

The loader begins to develop the deposit directly near the ore chute at the shortest transport distance, thus forming a radial slicing. After that, it comes to the next slice with a larger radius and so on. The extension of the radius continues until the transport length reaches the limit, which is usually assumed 500 m for wheel loaders. The aim of the proposed technology is in the constant minimization of the transportation distance of the mining mass from the face to the receiving tank of the open ore chute. So, we transfer the development of the mineral, which is to be transported to a larger distance, to the later period. As a result, discounted costs for the transportation also diminish.

Let's make a model of mining works on the technogenic deposit. The following mathematics calculation will be done for these purposes. The volume of the first slice will be calculated from the elementary formula of a half of an area of a circle $V=0{,}5\pi L^2 h_s$.

Now we will calculate the volume of every following slice according to the formula (1):

$$V = \frac{\pi(L^2-l^2)h_S}{2}, \qquad (1)$$

where L – radius of a current radial slice, m
l – radius of a previous radial slice, m
h_s – high level of a stage of the technogenic deposit, m

At the same time the volume of a slice is equal to the product of the loader's productivity to the time of the development. On the base of preliminary calculations, we can determine the time of the slice development according to the formula (2):

$$t = \frac{\pi h_S(L^2-l^2)}{2Q_{pn}}, \qquad (2)$$

where Q_{pn} – productivity of a wheel loader, m^3/t.

For the conditions of using the pneumatic wheel loader CAT-966L with the height of a stage 12 m we will make calculations for different transportation distances from 10 to 500 m with the step 10 m and tabulate the results in table 2.

Table 2. Calculation of working time of radial slicing for the pneumatic wheel loader

L, m	Q_{pn}, m^3/sh	Cumulative working time, sh	Time of radial slicing working, sh	Volume of radial slicing, m^3
10	20753,1	0,1	0,1	1885,0
20	18078,5	0,4	0,3	5654,9
30	16014,6	1,0	0,6	9424,8
40	14373,6	1,9	0,9	13194,7
50	13037,7	3,2	1,3	16964,6
…	…	…	…	…
470	2658,8	1115,8	65,9	175300,9
480	2609,3	1184,4	68,6	179070,8
490	2561,7	1255,8	71,4	182840,7
500	2515,7	1330,0	74,2	186610,6

On the basis of the received data, we can make a diagram of dependence of the transportation distance on the time, which was taken for the development of the radial slicing (Fig. 3).

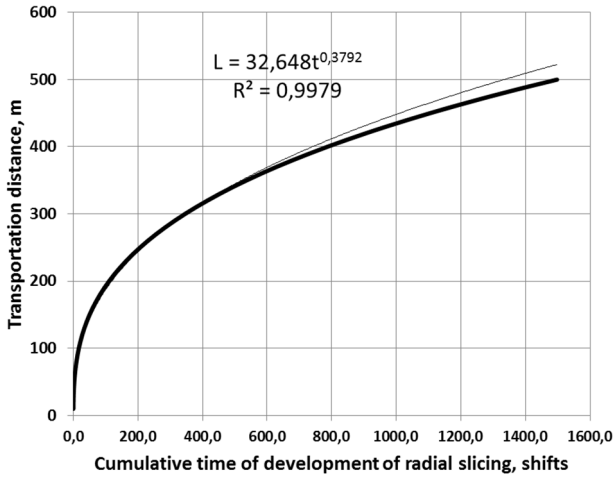

Fig. 3. The dependence of the transportation distance by the radial slicing on the time of the development.

This dependence can be described by the equation of the exponential function $L=32{,}648t^{0{,}3792}$. The obtained diagram allows approximately determine the rate of movement of mining works at the technogenic deposit and dynamically plan mining works on different stages.

On the one side, the proposed technology of development by radial slicing transfer transportation expenses to the later period, but afterwards it will require additional units of mining and transport equipment.

Calculations, performed in the previous sections, allowed to make a conclusion that the productivity of the loader will reduce while removing the face from the ore chute. This clearly shows the diagram of the loader productivity on the radius of the radial slicing (fig. 4).

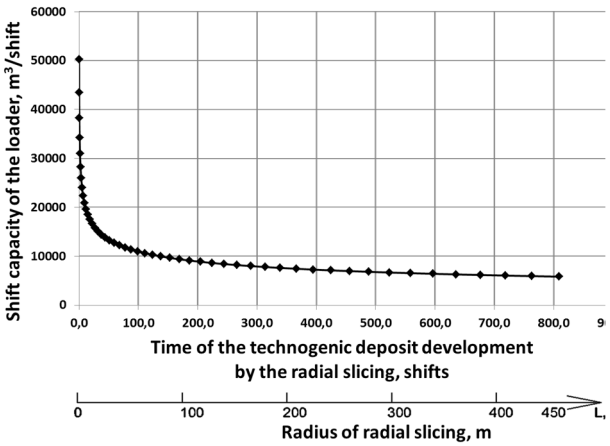

Fig. 4. The dependence of the shift capacity of the loader on the working time with increasing radial slicing radius.

As a result of the conducted researches there was an idea to reduce transportation distance by transferring the open ore chute. It will provide the rise in productivity and, consequently, will diminish the equipment stock and the development period of the technogenic deposit. During the periods of increasing transportation distance, the transfer of the ore chutes will allow to keep the equipment stock at a constant level.

However, there is a question of the step of its reinstalling. On the one side, an insufficient transfer step will result in a higher cost of dismantling and installation of the ore chute and the vibrating feeder. On the other side, the work with a long transportation distances increases operating costs.

So, the rational value of the transfer step should be determined by the economic criteria.

We describe mathematically the necessary condition of equality by the formula (3).

$$C \times t + EK = C \times (t - \Delta t) + EK + \Delta C, \qquad (3)$$

where C – specific operating costs for the loaders, ore chutes and feeders, USD/shift;
ΔC – additional operating costs for dismantling/installation of vibrating feeders and ore chutes, USD;
K – capital expenditures for loaders, ore chutes and feeders, USD;
t – time of working of the radial slicing according to the basic variant, shifts;
Δt – change (reduction) of working time due to the transfer of ore chutes, shifts;
E – norm. coefficient of reduction of capital expenditures.

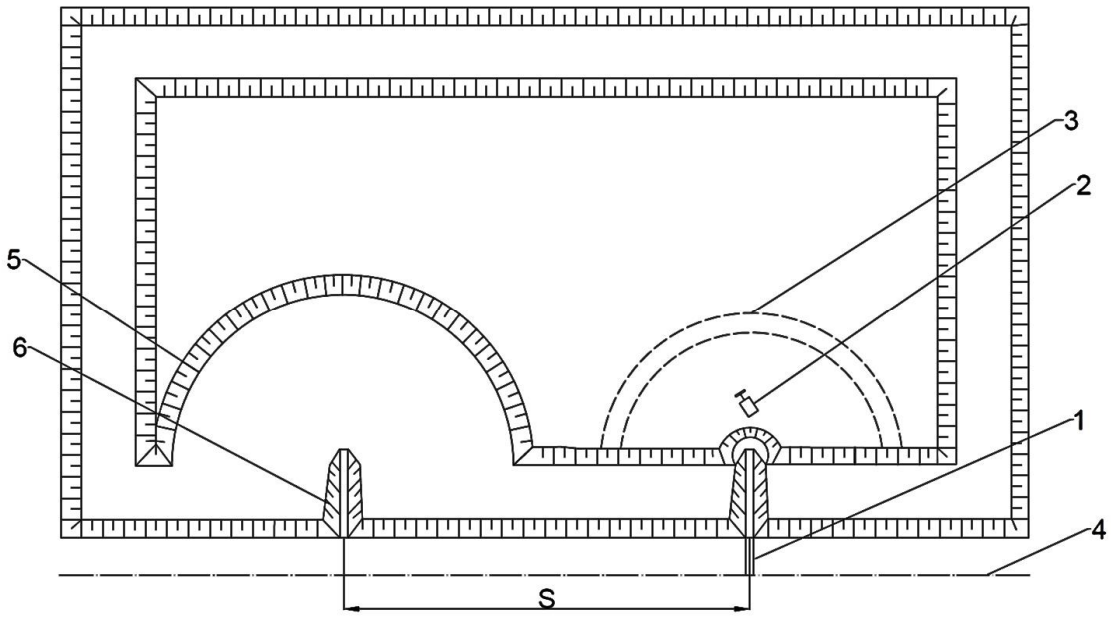

Fig. 5. Scheme of development of the technogenic deposit with reinstalling of the open ore chute: 1 – open ore chute in new in the current position; 2 – pneumatic wheel loader; 3 – radial slicing; 4 – axis of a railway transport; 5 – radial slicing for old open ore chute position; 6 – open ore chute in the old position; S – step of reinstalling of the open ore chute.

Let's simplify the expression, change the working time with respect to the volume change to productivity, which in turn also depends on the transportation distance and time, take into account the system of restrictions and obtain a mathematical model for the technogenic deposit in 2 stages and get formula (4):

$$\sum C \frac{\pi(L_i^2 - L_{i-1}^2)h_s}{2Q(t)_i} - \Delta C \rightarrow min \qquad (4)$$

$$\begin{cases} L_i \geq L_{i-1} \\ h_s = [8; 15], \end{cases}$$

where *i* – optimization is completed according to the number of radial slicing, every increasing *i* corresponds to the increase of the radius on 10 m.

Search of the optimal value of the transportation distance will be performed in MS Excel using the reduced gradient method. For the technogenic deposit in 2 stages with a height of a stage 12 m and a loader with a bucket capacity of 7.4 m^3, the maximum economically feasible transportation distance, which corresponds to the radius of the radial slicing, will be 183 m.

So, the scheme of development of the technogenic deposit with reinstalling of the open ore chute is given in the fig. 5.

However, it is obvious that the obtained result of the optimum transport distance should also be verified by the technological criterion, namely: the weighted average performance of the pneumatic wheel loader is to correspond to the performance of the vibrating feeder, as otherwise there will be technological downtime. In our case, the weighted average capacity of the loader is 7686 m^3/shift, and the vibration feeder is 7680 m^3/shift, which corresponds to the condition of equality. Thus, according to fig. 4, for these conditions, the step of reinstalling of the open ore chute *S* between axes of open ore chutes for the new and old positions will be equal 366 m as two radii of radial slicing.

4. Conclusions

The obtained model allows to minimize the cost for development of the technogenic deposit due to the reasonable timely transfer of the ore chute and productivity increase of the wheel loader. The obtained dependences allow to plan the dynamics of development of the mining front at the technogenic deposit.

Further studies will focus on identifying and optimizing other parameters of the elements of the development system and creating a classification for the development systems of technogenic deposits.

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Justification of the method of determination of the border overburden ratio

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Abstract. The economic efficiency of the enterprise and the length of its operation, the full utilization of mineral reserves and the total cost of operation depend on the selected depth and boundaries of opencast mining. In such conditions of the deposits' development it is necessary to evaluate the capabilities of the raw material base for the further development of the mining enterprise. The basis for determining of the border overburden ratio is on the condition that the price of manufactured marketable output of the designed enterprise should not exceed the price of the same marketable output in the world market. The realization of this condition is achieved analytically. This takes into account the impact of the rate of return on the final depth of the designed open pit. A new method of determining of the border overburden ratio is developed, which ensures the competitiveness of iron ore concentrate in the world market. The value of the border overburden ratio is developed for the Pershotravnevij open pit of the Northern mining and processing plant, depending on the situation of the iron-containing products' prices, which ensures the competitiveness of marketable iron-ore output in the domestic and world markets.

1 Introduction

The economic efficiency of the enterprise and the operation period, the full utilization of mineral reserves and the total cost of operation depend on the selected depth and boundaries of the opencast mining.

Nowadays, in the development of steeply falling iron ore deposits, their working contours on the surface have reached design marks on the most open pits. Mining development occurs only when they are lowered. In such conditions of the deposit development it is necessary to evaluate the capabilities of the raw material base for the further development of the mining enterprise.

When choosing opencast mining alternatives, their main parameters – open pit boundaries, mining mode and ore productivity – are assessed by economic indicators. These indicators are: profit from sales of saleable output; production costs of the saleable output; profitability, etc.

As practice shows, the depth and position of the final boundaries of the most large open pits as the mineral deposits are worked out are repeatedly revised and adjusted. However, it is imperative to determine the final boundaries of the open pit mining in which the development of open pit deposits will be effective. There is a concern about the designing a new enterprise, when similar mining companies are already operating.

Recent applied and scientific studies on this issue clearly indicate the need to re-evaluate the final boundaries of Ukraine's open pits [1-3]. The development in the approved by existing designs boundaries can lead to the rapid depreciation of the loading faces of the open pits on the final designed boundaries in the near future. And this will entail a significant increase in the cost of the opencast mining due to the reactivation of non-working faces, if the open-pit boundary will be redefined in future.

At present, there are a lot of methods in the theory and practice of design to determine the border overburden ratio and open-pit boundaries that develop steep-dipping banks. Today, the open pit boundaries are determined on the basis of a comparison of one of the overburden ratio of the designed open pit with the border overburden ratio. At the same time, to determine the border overburden ratio, economic indicators of the cost of ore underground mining method or the wholesale price of the mineral are most often used. However, in the world market of commodity iron ore products the only indicator of its competitiveness is price. Production costs and profitability are commercial secret. Therefore, the main condition for a comparative assessment of the operational efficiency of mining and processing plant in the world market is to compare the price of marketable products with the price of the same marketable products in the world market.

2 Object and methods of research

A great number of scientists were engaged in the questions of determining the open pit boundaries. The largest contribution [4-11] in the theory of designing the boundaries of open-cast mining is owned by

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A. I. Arsentyev, V. V. Rzhevskij, B. P. Yumatov, V. S Hohryakov, V. G. Bliznyukov, A. K. Polishuk, Yu. I. Anistratov.

Designers and scientists use the main criteria for evaluating [9-10] the boundaries of effective mining of open-pit deposits use the cut-off (economically viable) overburden ratio as the main criterion, which is the maximum permissible overburden ratio, according to which open-pit mining in these specific conditions economically feasible.

There are several well-known principles to justify the depth of the open pits, based on the comparison of one of the overburden ratio (average, initial, contour, current, mid-operational) or the sum of these coefficients with the cut-off (economically feasible) overburden ratio.

The economic basis of all calculation principles for determining the boundaries of the open pits is to compare the possible cost of ore mining with the expected over the designed open pit [12], and the cut-off overburden ratio of the overburden is calculated by the technical and economic indicators achieved at the mining enterprises at the time of design.

In this case, to determine the cut-off overburden ratio, the most commonly used economic indicators of the cost of ore mining by underground method or the wholesale price of minerals.

However, it should be understood that comparing the cost of open and underground mining is not correct due to the different production volumes; the open pit productivity is much higher than the productivity of mines, which to a different extent covers the needs of the market. In addition, the cost of mining by underground method remains equally high throughout all the service life, while the open pit reaches a production cost peak in only one of the operating periods at which the surface boundaries reach the final pit.

Recently, studies have been conducted on the determination of prospective mining boundaries of the open pits: the Scientific and Research Mining Institute (SRMI) [1, 13]; The Academy of Mining Sciences of Ukraine [2] and Kryvyi Rih National University (KNU) [3]. The determination of the cut-off overburden ratio was performed by these institutes on the basis of comparison of indicators of work of the investigated enterprise with indicators of enterprises with the underground method of mining, as well as with indicators of similar mining and processing plants. The price of the marketable products (concentrate), which depends on its quality, has always determined the boundaries of opencast mining. However, at different mining enterprises, marketable products of the same quality may have different selling prices [14], which in turn may make an error in determining the final boundaries of the open pits. Therefore, in the paper [15] it was proved contractual factors influence on the price of commodity products, which makes inaccurate application of existing methods for determining the final open pit boundaries.

However, the existing methods of determining the cut-off overburden ratio [16-18] do not take into account the competitiveness of the iron ore products of the designed enterprise in the world market.

At present, the strategic assessment of the interaction of the company with the external environment we must first take into account the qualitative and quantitative impact of competitors and demand on pricing [19], and, accordingly, the profit of the enterprise [20]. With different levels of the competitive environment and the supply-demand relationship, different options for choosing mining company strategy and, accordingly, a suitable methodology for selecting the final open pit outline.

Therefore, the goal was to develop a method of determining the cut off overburden ratio, which will allow while the formation of the price for iron ore products on the world market to determine the boundaries of the open pit, that ensures the competitiveness of mining and processing plant.

To achieve this goal, a complex research method was used in the work, which includes theoretical and instrumental methods: analysis and theoretical generalization of enterprises reports, scientific and technical publications and other information sources in the field of determining the boundaries of careers in substantiating the problem and task of research; system analysis in researching career indicators; analytical, graphical and graphoanalytical methods of the research of technological and economic interconnections of the mining mode and the productivity by minerals in determining the boundaries of the career; economic and mathematical modeling of career options.

3 Results

The only indicator of the competitiveness of the marketable iron ore products is its price. Therefore, the main condition for a comparative assessment of the designed mining and processing plant in the world market is to compare the price of finished product with the price of the same product in the world market. Hence, the basis of the determination of the cut-off overburden ratio will be the condition that the price of the finished product of the designed enterprise does not exceed the prices of the same marketable products in the world market, which is represented by inequality:

$$P_c^d \leq P_c^W \quad (1)$$

where P_c^d – the price of the concentrate of the designed mining and processing plant, UAH/t; P_c^W the price of the concentrate in the world market, UAH/t.

At any mining enterprise we plan the profit margin, which is expressed by the final sum of production profitability of the enterprise. Therefore, the price of the concentrate of the designed mining and processing plant can be represented as:

$$P_c^d = C_c^d \cdot (1 + \psi), \text{ UAH/t}, \quad (2)$$

where C_c^d – the prime cost of the concentrate of the designed mining and processing plant, UAH/t; ψ – target profit marginy, parts un.

The cost of production of the concentrate of the designed mining and processing plant will be represented by the expression:

$$C_c^d = \frac{a_m^d + a_c^d + b^d \cdot n}{\gamma_c^d}, \text{ UAH/t}, \quad (3)$$

where a_m^d – the cost of ore mining without the expense of the overburden in the designed open pit, UAH/t; a_c^d – the cost of the ore conversion to the concentrate at the designed mining and processing plant, UAH/t; b^d – the cost of the overburden in the designed open pit, UAH/m^3; n – the overburden ration in the designed open pit, m^3/t; γ_c^d – concentrate output from one ton of ore to the designed mining and processing plant, parts un.

On this basis, the expression of determination of the concentrate price of the designed mining and processing plant (2) will take the following form:

$$P_c^d = \frac{a_m^d + a_c^d + b^d \cdot n}{\gamma_c^d} \cdot (1 + \psi), \text{ UAH/t}. \quad (4)$$

The price of concentrate, which is on the world market, depends on the content of iron. Therefore, the price of the concentrate of the designed mining and processing plant should be brought (in terms of the content of iron) to the price of the base enterprise (the price of concentrate and its iron content in the world market). Then the expression will look like this [1]:

$$P_c^{\prime d} = P_c^W \cdot \frac{\beta^d}{\beta^W}, \quad (5)$$

where $P_c^{\prime d}$ – the present value of the concentrate of the designed mining and processing plant at the price of concentrate and the content of iron in it on the world market, UAH/t; β^W i β^d – iron content in the concentrate in the world market and designed mining and processing plant, accordingly, parts un.

On this basis, the price of the designed concentrate will be defined as:

$$P_c^{\prime d} = \frac{\beta^d \cdot (a_m^d + a_c^d + b^d \cdot n)}{\gamma_c^d \cdot \beta^W} \cdot (1 + \psi), \text{ UAH/t}. \quad (6)$$

Based on formula (2), the cost of concentrate on the designed mining and processing plant as an indicator of competitiveness, depends on the planned profit and volume of overburden works. Other indicators are determined by the level of technology and technology of ore and dead rocks mining (a_m^d i b^d), achieved at the enterprise, indicators of technology for ore conversion to concentrate and quality of ore (a_c^d, γ_c^d, β^d).

These indicators in determining the competitiveness of similar companies, can be taken constant, as they do not change for a long time, and if they change, then at almost the same rate. For example, let's consider the graphs of the change in the price of concentrate of the North mining and processing plant from the current overburden ratio with different iron content in concentrate in the world market (Fig. 1, 2).

From the presented pictures we can see that while maintaining the profitability of the enterprise at the same level, with the increase of the overburden ratio, the price of production should increase. With a constant overburden ratio, increasing profitability is possible only with the increase of the price of products.

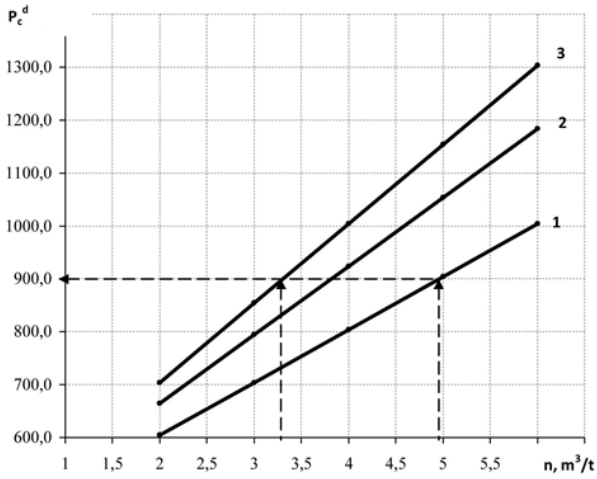

Fig. 1. Changes in the price of the concentrate of the Northern mining and processing plant, depending on the current overburden ratio when the iron content of the concentrate in the world market 65%: 1 – at the rate of profit ψ = 0 %; 2 – when ψ = 30; 3 – when ψ = 50.

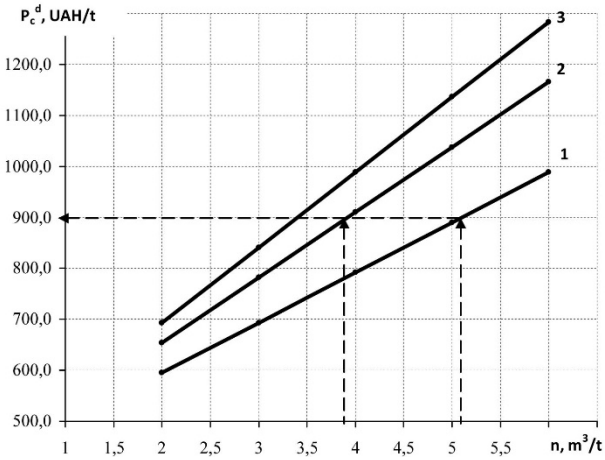

Fig. 2. Changes in the price of the concentrate of the Northern mining and processing plant, depending on the current overburden ratio when the iron content of the concentrate in the world market 66%: 1 – at the rate of the profit ψ = 0 %; 2 – when ψ = 30; 3 – when ψ = 50.

Thus, with the increase of the overburden ratio and with the increase of the profitability of the enterprise, the price of production of the designed enterprise will increase. There will come a time when the price of production will rise to the limit value P_c^W. Then, substituting in the condition of competitiveness of marketable product of the designed pit (1), the value of its possible price, we obtain:

$$\frac{\beta^d \cdot (a_m^d + a_c^d + b^d \cdot n_{c.o.}) \cdot (1+\psi)}{\gamma_c^d \cdot \beta^W} \leq P_c^W. \quad (7)$$

Based on this inequality, the cut-off overburden ratio is defined as:

$$n_{c.o.} = \frac{\frac{P_c^W \cdot \gamma_c^d \cdot \beta^W}{\beta^d \cdot (1+\psi)} - (a_m^d + a_c^d)}{b^d}. \quad (8)$$

In the table 1 we report the present value of the concentrate of the Northern mining and processing plant calculated by the formula 6.

Table 1. The price of concentrate on the world market and the price of the concentrate of the Northern mining and processing plant depending from the iron content.

Iron content in the concentrate, %	The price of the concentrate, UAH/t	
	In the world market	Discounted value Northern MPP
62	1086,4	1150,2
63	1127,0	1174,2
64	1167,2	1197,1
65	1208,0	1219,9
66	1248,0	1241,2

Substituting the value of economic and technological indicators of the Northern mining and processing plant in expression (8), we determine the cut-off overburden ratio with different values of profitability (profit rate: 1 – 0%; 2 – 10%; 3 – 20%; 4 – 30 %; 5 – 40%; 6 – 50%). This is shown in Fig. 3. The points in the Fig. 3 correspond to the iron content of the concentrate on the world market.

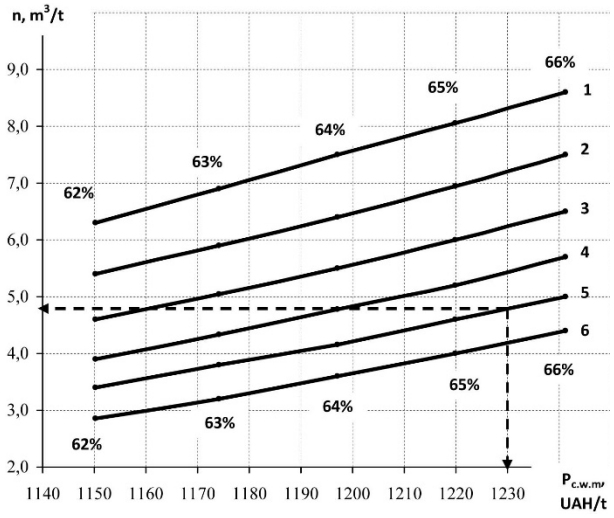

Fig. 3. The dependence of the cut-off overburden ratio on the price of concentrate in the world market: 1 – at the profit rate ψ = 0%; 2 – with ψ = 10%; 3 – with ψ = 20%; 4 – with ψ = 30%; 5 – with ψ = 40%; 6 – with ψ = 50%.

In Fig. 4 we present the dependence of overburden ratio from the profit rate for the working conditions of the Pershotravnevij open pit of the Northern MPP.

For example, it is necessary to find out what the price of a concentrate with an iron content of 65.5% at a rate of 40% will be. To do this, on the curve with the required norm of the profit (curve 5, Fig. 3) we find a given value of iron content. From the value of the desired iron content (between the group of vertical points 65% and 66%), lower the perpendicular (dashed lines, Fig. 3) on the y-axis and abscissa and determine the values of the overburden ratio and the concentrate price. That is, with an iron content of 65.5% and a profit rate of 40%, the overburden ratio will be 4.8 m³/t, and the price of concentrate – 1228 UAH/t.

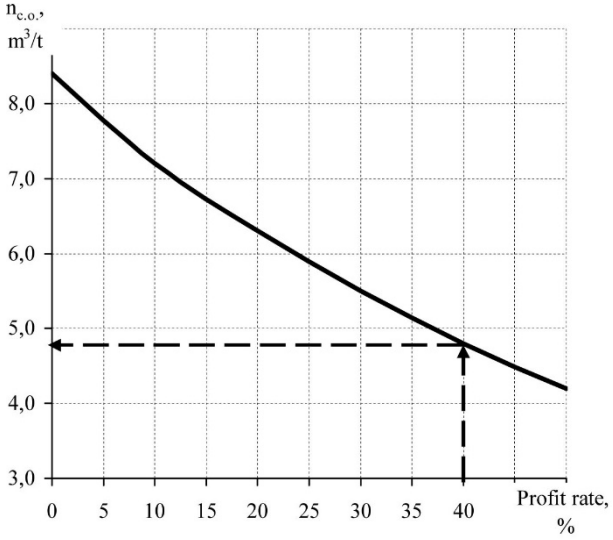

Fig. 4. The dependence of the cut off overburden ratio on the profit rate for the working conditions of the Pershotravnevij open pit of the Northern mining and processing plant.

Studies on theoretical open pits and powerful iron ore open pits of Kryvbas have shown that the accuracy in determining of the open pit boundaries that do not take into account market conditions is up to 50%. Thus, it was determined that in order to more accurately determine the open pit boundaries, it is not necessary to take into account the levels of competition, supply and demand. However, in light of the fact, that it is difficult to predict economic indicators with a high degree of accuracy, it is necessary to move from difficult-to-predicted economic indicators to more stable technological ones when determining the pit outline.

Such technological indicators may serve changes of the ore volumes and overburdens in open pits-competitions.

In this regard, before designing it is important to carry out analytical work, to make forecasts about the future conditions of competition and demand, as well as changes in price trends and cost of marketable product. At the design stage, it is important to work out the most likely scenarios, and the economic effectiveness of the variants of the final pit boundaries must be determined taking into account the risks of the probably change in the market conditions.

4 Conclusions

A new method of determination of the cut-off overburden ratio has been developed, that allows the determining while the world market price of iron ore products to determine the open pit boundaries, which ensure the competitiveness of mining and processing plant. According to the developed method, the values of the cut off overburden ratio for the Pershotravnevij open pit of the Northern mining and processing plant were determined, which ensure the competitiveness of iron ore

marketable product in the world market at different values of the profit rate. Thus, this principle of defining the boundaries of opencast mining takes into account the dynamics of the external competitive environment of the mining enterprise.

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Development of resource-saving technology when mining ore bodies by blocks under rock pressure

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Abstract. The article aims to develop the resource-saving technology when mining steep ore bodies applying 250 mm-diameter boreholes to break ore into the compressed environment. This will reduce dilution of the mined ore mass in conditions of rock pressure around blocks. When mining iron ore deposits of Kryvyi Rih basin, applied mining systems allow for creation of the compensatory space as the first stage. However, these stopes fail under rock pressure, this influencing negatively ore breaking and extraction. The degree of extraction can be increased through breaking ore mass into the compressed environment. The width of the ore layer to be broken onto the compressed environment is determined through industrial investigations. To enhance breaking conditions, it is suggested to apply boreholes of a larger diameter. However, there is no technique developed for determining thickness of the ore layer to be broken depending on the borehole diameter and the fragmentation factor. When applying 250 mm boreholes, increase of thickness of the layer to be broken from 2 to 10 m is found to cause compaction of the previously broken layer up to 3 m with the optimal ore fragmentation factor of 1.3–1.5 and 3-fold decrease of lumps yield. This results from the fact that drilling a 250 mm borehole to secure even provision of the massif with explosives reduces the line of the least resistance.

1 Introduction

Kryvyi Rih iron ore basin accounts for over 32.2 bn t of iron ores with iron content in the massif of 24-65% that are mined by underground and open-pit methods. Iron ores with the useful component content of 60-65% are mined applying bulk-caving methods on the compensatory area or open stoping and further caving of enclosing rocks [1-4].

Underground mining of ore bodies is performed at the depths of 1220–1350 m. Geometric parameters of ore bodies are as follows: along the strike length is 800–1200 m; thickness is 30–120 m; dip angles are 45–85° [5-7].

Mining operations are performed in the following order: the ore body is vertically divided into levels of 75–90 m high; it is mined along the strike from the center to its flanks or from the flanks to the center. Nevertheless, because preparation operations are behind schedule, mining enterprises do not keep to this order that results in concentration of stresses around the block and decreased ore extraction [8-10].

Works [11-15] suggest various options of mining systems enabling increase of extraction of ore mass from stope blocks. However, blocks fail under the influence of rock pressure when forming the compensatory area, thus causing increased mining costs and time.

To increase iron content in the muck, it is suggested to concentrate the mass at surface crushing and sizing plants. [16-18]. It should be considered that in terms of mineralogical composition there are 6-9 varieties of ore, each requiring special treatment. At present, there are developed and successfully implemented various automated complexes due to which the useful component content in ore mass increases by 3–6% (i.e. from 56% to 62%) [19-21]. This updating trend is based on force impacts on the substance during disintegration in the activator but it does not consider processes connected with underground mining of the useful mineral [22-25]. Constantly improved software of the automated complexes indicates iron content in real time and is able to split ore mass flows by quality.

Nevertheless, all these measures inevitably result in increased mining costs (by 2–7%), decreased annual output of the mine (by 10–20%) and alienation of agricultural lands for external dumps.

Therefore, to decrease mining costs, a technology should be developed to mine blocks in complicated mining and geological conditions without increase of mining costs.

For successful mining of blocks with unfavourable conditions around them, it is reasonable to apply bulk-caving systems without creating significant exposures. Such system is used at Kiruna mine (Sweden) [26-28].

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The point of the system is in the decreased sublevel height and borehole breaking onto the compressed environment with end drawing due to which the amount of pure undiluted ore mass mined increases [29-32]. However, a considerable number of haulage workings require additional expenses.

When implementing this technology at underground mines of Kryvyi Rih iron ore basin, labour conditions deteriorate and costs for maintaining workings grow because of complicated mining and technical conditions [33-36].

To reduce costs for maintaining main openings, mines implement modern methods of monitoring the rock massif state while disturbing it by underground operations [37-39].

It is also possible to reduce costs on maintaining workings at the expense of breaking ore by deep boreholes onto the compressed environment.

When breaking ore on the compressed environment, the surface of the working is in direct contact with the rock massif and, therefore, the elastic wave from one environment moves into another, into the incident energy. Reaching the fragmentation factor (K_f = 1.3 – 1.4), part of the direct energy is used to destroy the rock massif (75 – 90%), and part (10 – 25%) - to compact the material. Displacement of the compressed material in the stope occurs after blasting of the first ring of holes and reaches 3 m at 4–5 row blasting (or blasting 3 rows of parallel contiguous borehole rounds) and then stops. Material compaction occurs within the 25 – 30 m wide area if ore hardness is average and does not exceed 15 m if rocks are hard [40,41].

Partial drawing of caved ore creates necessary loosening of rock mass before breaking. The number of rows for blasting should be sufficient for the material not to be excessively compacted.

However, application of borehole breaking with the diameter of holes of 105 mm increases expenses on drilling as the number of borethole rings increases 2–3-fold.

2 Methods

Based on the conducted critical analysis of works dealing with issues of increasing ore mass extraction in conditions of rock pressure around blocks, the following conclusions can be drawn:

1. The authors suggest increasing the iron content in ore mass at the expense of a mining and concentrating complex or through applying the selective energy saving technology aimed at excluding the concentration process or creation of the compensatory area of various shapes. This will unavoidably result in increased mining costs and, consequently, loss of the world market.

2. Decrease of dilution and increase of extraction without increased mining costs can be reached through replacing the mining system by that without a compensatory area. However, this requires considerable expenses on workings and their maintenance.

Thus, it is necessary to enhance the technology of underground mining of blocks under rock pressure around them to ensure efficient extraction and decreased mining costs.

3 Results and discussion

The technique of determining the line of the least resistance and distances between borehole ends should be applied when determining parameters of blasting and drilling operations [25, 36, 37, 40].

Such techniques differ in breaking conditions and estimation criteria. Thus, when mining iron ore deposits, there are applied methods based on placing explosives in the massif depending on stress concentration, rock hardness, qualitative characteristics of explosives, etc [15, 16, 37].

Analysis of methods of determining parameters of drilling and blasting enables building dependencies of changes in the line of the least resistance on the borehole diameter when using *Grammonite 79/21*, Fig. 1.

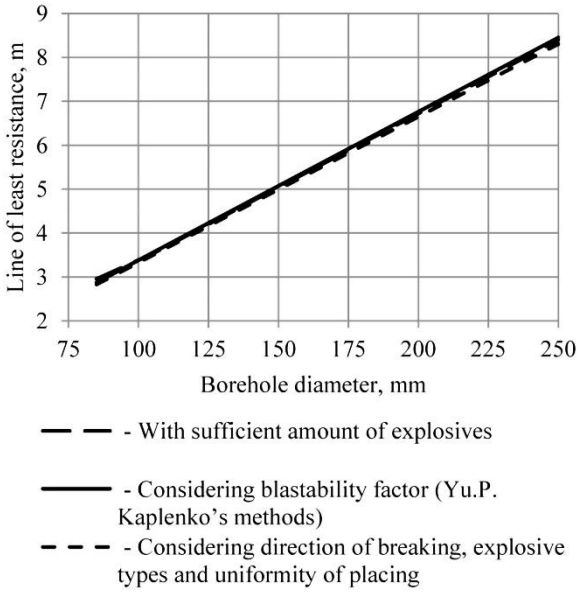

Fig. 1. Dependencies of changes of the line of the least resistance on a borehole diameter when applying various calculating methods.

The graphs in Fig. 1 demonstrate that the analyzed methods for determining the line of the least resistance do not differ significantly from each other and the error does not exceed 20%. Therefore, the new technique developed by Yu. P. Kaplenko is used for further investigations and calculations. The technique is widely applied at the underground mines of Kryvyi Rih iron ore basin [37].

The line of the least resistance (LLR), the distance between borehole ends and specific consumption of explosives for breaking in terms of ore hardness are determined by the formulas [37]:

$$W = k_n \times C_o \times d_{pr}, \text{ m}; \quad (1)$$

$$a = m \times W, \text{ m}; \quad (2)$$

$$q = \frac{2 \times k_z \times U}{a \times W \times \gamma}, \text{ kg/t}. \quad (3)$$

The results of the calculations enable building a dependency of LLR (Fig. 2), the distance between borehole ends (Fig. 3) and specific consumption of explosives for breaking (Fig. 4) on the diameter of the borehole and the ore hardness factor.

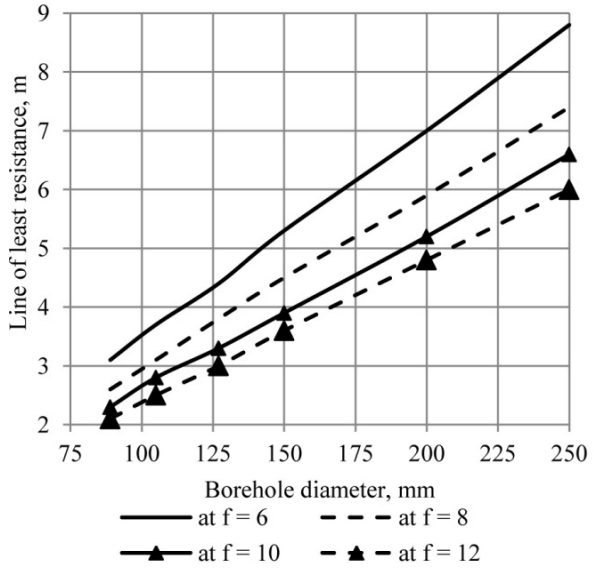

Fig. 2. Dependencies of LLR on the borehole diameter and the hardness factor.

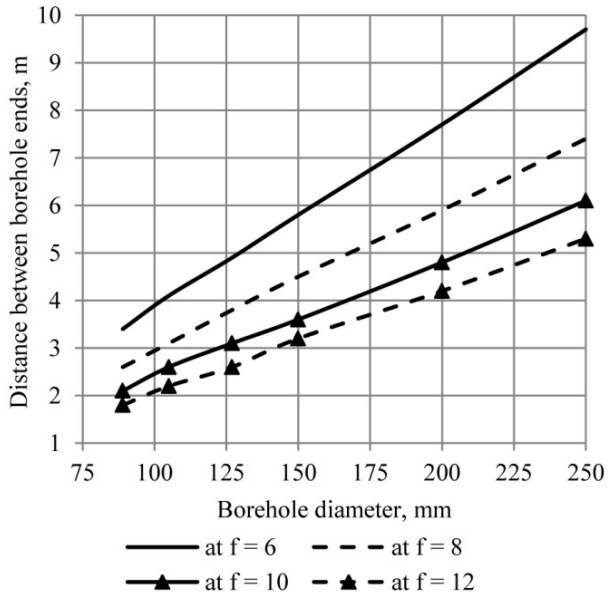

Fig. 3. Dependencies of the distance between borehole ends on the borehole diameter and the ore hardness factor.

The graphs in Fig. 2 demonstrate that with rock hardness of 13 and the borehole diameter from 89 mm to 250 mm, LLR increases from 2.1 to 6 m and specific consumption of explosives grows from 0.8 to 0.9 kg/t (see Fig. 4).

The graphs in Fig. 3 demonstrate that with the increase of the borehole diameter from 89 to 250 mm the distance between borehole ends grows from 1.8 to 5.3 at the ore hardness factor of 12.

Thus, when ore hardness increases, the line of the least resistance, the distance between borehole ends and specific consumption of explosives for breaking grow. This corresponds to the practice of using *Grammonite 79/21* when mining iron ores at Kryvyi Rih basin.

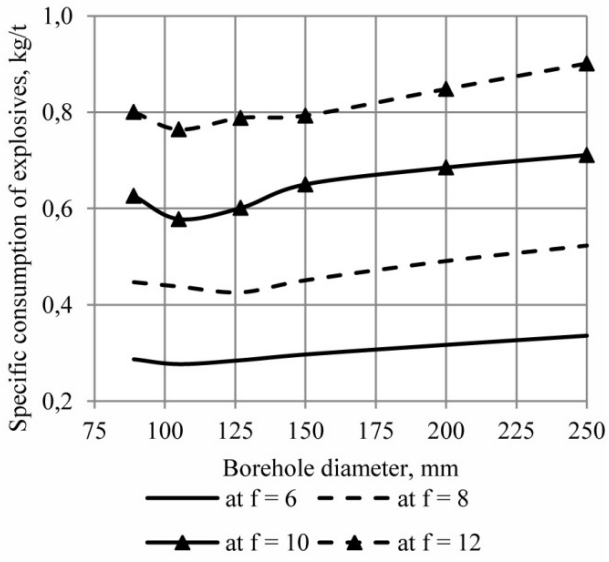

Fig.4. Dependencies of specific consumption of explosives for breaking on the borehole diameter and the ore hardness factor.

According to research data [36], displacement of the compressing material in the stope makes 2–2.5 m after explosion of the first row of boreholes and reaches 3 m after explosion of 4–5 rows of boreholes (or 3 rows of parallel contiguous boreholes) and then it stops. Compaction occurs in the stope area with the width of 25–30 m (or 60–80 m at the average ore hardness and rather thick ore bodies). According to the investigation results, movement of the previously broken ore or caved rock of the adjacent panel on which the ore is broken makes 1–1.2 m [36].

Displacement of the compressed material depends, first of all, on thickness of the ore layer to be caved. Displacement and compaction occur unevenly depending on the distance from the compressing material; so the farther the distance from the contact separating caved rocks and ore massif is, the smaller displacement and compaction are.

Change of the compressing rock layer from 25 to 15 m does not produce any noticeable impact on the fragmentation factor of ore and rock on the contact. Major displacement occurs not far (2 – 15 m) from the contact. Besides, after the first explosion, compaction and movement of the material occur not far from the contact surface. After subsequent explosions, displacement of the compressing material decreases as forces of internal friction and adhesion that appear in the compacted compressing material obstruct displacement of caved ores and rocks [36, 40].

Displacement of the compressed material in the compressed environment depends on the fragmentation factor of ore mass and thickness of the caved compressing material. The volume of the compressing material after movement is calculated by the expression [36]

$$V_1 = (L - \Delta t) \times h \times M, \text{ m}^3, \quad (4)$$

where *h, L, M* are height, width, thickness of the mining block, m; Δt is thickness of the layer when breaking in the compressed environment, m.

Transformations of expression (4) considering volumes of the layers that are broken and over-compacted with the corresponding primary fragmentation factor result in the following expression for determining thickness of the layer when breaking in the compressed environment

$$\Delta t = \frac{L \times (K_r - K_{r1})}{K_r}, \text{ m}, \quad (5)$$

where K_r, K_{r1} are the fragmentation factors in the block and the compacted layer respectively

Possible displacement of the compressed layer considering the factor of ore fragmentation in the compressed layer is determined by the formula

$$l = \frac{\Delta t}{(K_{u.r} - 1)}, \text{ m}, \quad (6)$$

where $K_{u.r}$ is the average factor of ore fragmentation after blasting.

It should be noted that in laboratory conditions this formula is only true if width of the broken layer does not exceed 15 m. Calculations by formula (6) enable building dependencies of changes in thickness of the layer onto which ore is compressed on that of the broken ore massif layer, Fig. 5.

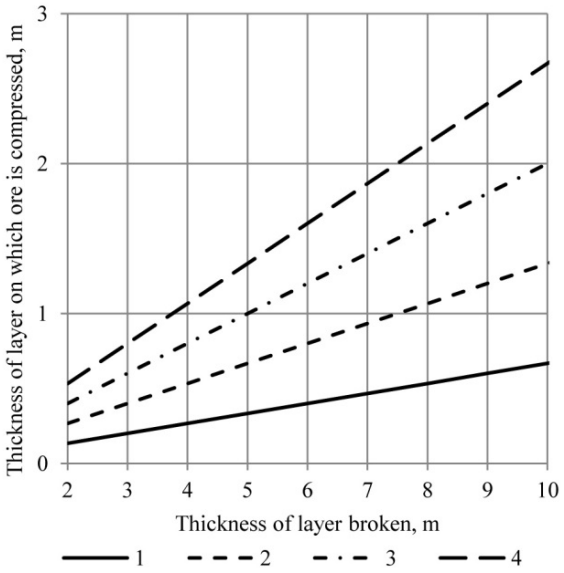

Fig. 5. Dependency of thickness of the ore layer onto which broken ore is compressed on that of the broken ore at the fragmentation factor of caved ore in the over-compacted layer of: 1, 2, 3, 4 – 1.4, 1.3, 1.2 and 1.1 respectively.

The graphs in Fig. 5 demonstrate that increase of the layer of the ore massif to be broken causes increase of the compressing layer width at the sufficient supply of the massif with explosives (i.e. simultaneous firing of 3 rows of parallel contiguous borehole rounds).

Thus, increase of the width of the layer of ore to be broken from 2 to 10 m causes increase of thickness of the compressing layer from 0.3 to 2.7 m at the decreased primary fragmentation factor in the over-compacted layer from 1.4 to 1.1.

The compaction factor mainly depends on the amount of explosives for ore breaking and compaction.

Transformations of equation (5) and its solution with respect to t_{st} result in the general formula for determining thickness of the ore layer to be broken on caved rocks in the upper part of the block

$$t_{st} = \frac{h \times (K_r - K_{r1})}{K_r \times (K_r - 1)}. \quad (7)$$

Analysis of the expression enables concluding that in practice thickness of the compressed material layer should be determined applying the grapho-analytical method.

Dependencies of thickness of the broken layer on height of the caved layer and the primary fragmentation factor in the over-compacted layer at the primary fragmentation factor of 1.5 are given in Fig. 6.

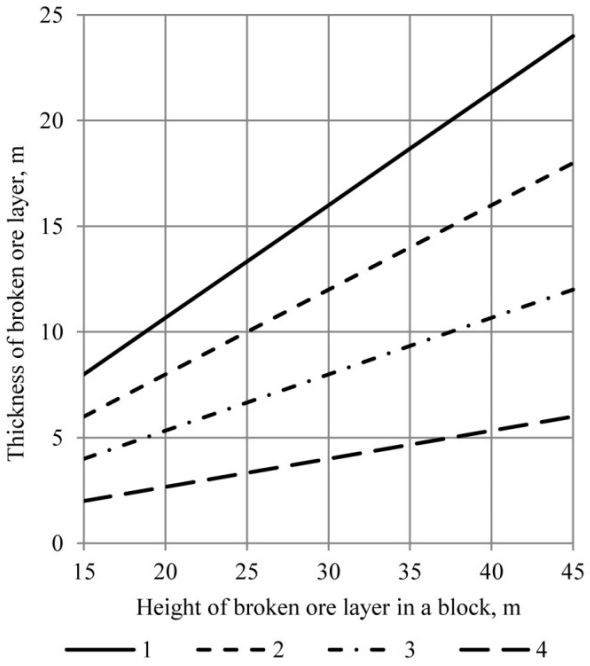

Fig. 6. Dependencies of thickness of the broken layer on height of the caved layer and the primary fragmentation factor in the over-compacted layer at the primary fragmentation factor of the caved layer of 1.5: 1, 2, 3, 4 – the primary fragmentation factor in the over-compacted layer is 1.1, 1.2, 1.3 and 1.4 respectively.

Fig. 6 demonstrates that increase of the broken ore thickness (stope height) causes possible increase of thickness of the layer to be caved. Thus, at the necessary factor of primary fragmentation of the over-compacted layer of 1.2, increase of the caved layer height from 15 to 45 m results in growth of thickness of the caved crown from 6 to 17 m.

When drawing under caved rocks from panels with inclined walls, part of the ore does not enter the area with drawpoints as ore drawing under the caved rocks is conducted at the angle of 60–85°.

It should be noted that expression (7) is true when the block is not impacted by external forces. At underground

mining of deposits, rock pressure caused by caved rocks located over the caved ore layer changes depending on the depth of mining, Fig. 7.

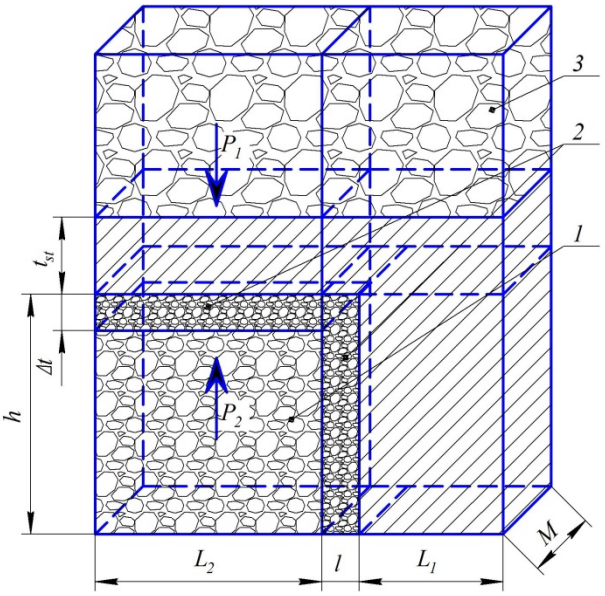

Fig. 7. The chart for determining displacement (movement) of the material to be compressed depending on the caved ore layer considering impacts of external forces.

On this basis, thickness of the layer of ore broken onto caved rocks considering pressure around the mining block is determined by the formula

$$t_{st} = \frac{h\times(K_r - K_{r1})}{K_r\times(K_r - 1)} \times K_\sigma, \text{ m}, \quad (8)$$

where K_σ is the factor considering rock pressure around the mining block.

The pressure coefficient is determined by relation of rock pressure around the block before and after crown caving and calculated by the formula

$$K_\sigma = \frac{P_1^/}{P_1}, \text{ m}, \quad (9)$$

where P_1 is pressure on the crown before its caving, MPa; $P_1^/$ is pressure on the block after crown caving, MPa.

It should be noted that formula (9) is true when the marginal condition is fulfilled

$$P_1 \geq P_2 \leq P_1^/. \quad (10)$$

Analysis of formula (8) enables concluding that:
- when pressure in the upper part of the mining block decreases, after caving the crown, movement of rock mass is observed in both directions (according to the research into breaking ore in the compressed environment) [21, 26, 40]. That is, not only caved ore but also caved rocks will be compacted;
- when pressure in the upper part of the mining block increases, after caving the crown, rock mass will move towards areas with lower rock pressure [36-40].

Harmful influence caused by borehole shooting in the ring can be decreased through out-of-turn borehole firing in the ring.

Quality of ore breaking depends on even distribution of explosives on the whole area of ore to be broken.

The conducted investigation enables suggesting bulk caving of ore and overlying rocks with breaking ore on the compressed environment by deep boreholes of 250 mm in diameter (Fig. 8).

This option of mining systems implies the following. The deposit is divided into 50–60 m long blocks along the strike. Vertically, a level is divided into 2-3 sublevels depending on the dip angle of the ore body.

Preparation of a block starts from driving access crosscuts from the haulage entry and drilling ventilation and manway raises on the block sides, Fig. 8. Then, ventilation and manway crosscuts are driven from the ventilation and manway raises. Service and ore discharge raises are driven to the crosscuts from the haulage level.

Two scraper entries are driven from the ventilation and manway crosscuts at the distance of 10 m from each other. The scraper entries are connected by the ventilation crosscut. 7 m high drawpoints go out of the scraper entry to the undercut level. Then, at the distance of 10 m from the scraper level, a drill drift is driven in the footwall. After that, stoping is performed.

Above the scraper level, a slot is formed through driving a 3 m wide cut raise and then 105 mm diameter boreholes expand it to the thickness of the ore body. Then, blast holes are drilled for draw points. After that, blast holes and boreholes are fired and part of the broken ore is drawn from the block.

Next, a sublevel is drilled by rings of deep boreholes from the drill drift. Breaking of the panel reserves starts immediately after creating the slot.

The drilling rig NKR-100M is used to drill 2 rings of deep boreholes of 250 mm in diameter from the drill drift. Then, the boreholes are charged and fired.

The block massif is drilled by drilling rigs with a reamer. First, a pilot hole of 155 mm in diameter is drilled, and then the hole is reamed to 250 mm. The P150S downhole hammer and the KNSH-155 bit are used for drilling. The reamer K-250 is used to ream the borehole to 250 mm [36,40].

In conformity with the determined parameters of the slot and the ore layer of the massif to be broken, the primary fragmentation factor is 1.35. To blast the massif, millisecond-delay and delay-action electric detonators are used. After caving the first ore layer and creating the over-compacted layer, 20% of ore is drawn. Next, 4-8 rings of deep boreholes are drilled and blasted.

After caving the main part of the reserves, the crown is caved through drilling rings of deep boreholes onto the caved ore compacting the upper and lower layers, Fig. 8.

After the block is broken, ore is drawn and hauled at the receiving level by the scraper winch 30LS-2S into ore passes and then vibrating feeders ASHL-2 load it into cars VG-10A.

It should be noted that when breaking onto the compressed environment by 105 mm boreholes, breaking by parallel contiguous boreholes is applied, i.e. 2 rings are drilled in parallel. In case 250 mm boreholes are applied, distance between their ends is decreased, Fig. 8.

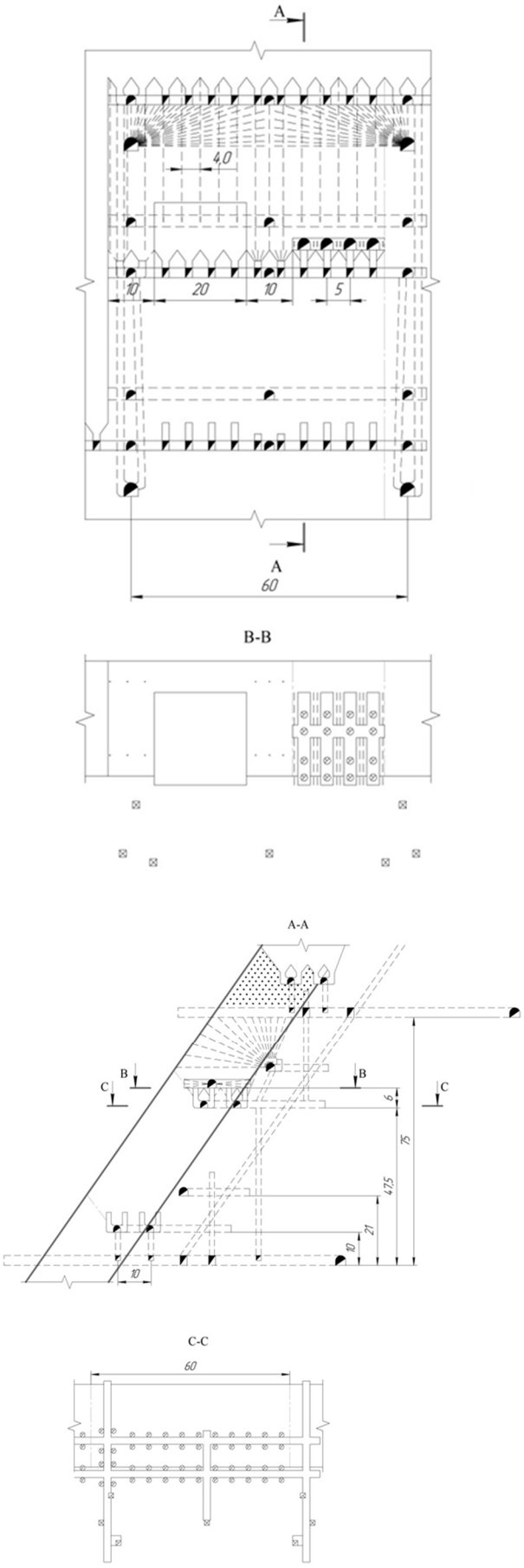

Fig. 8. Drilling by vertical rings of deep boreholes of 250 mm in diameter onto the compressed environment.

The results of the calculations of blasting and drilling by deep boreholes of 105, 250 mm in diameter with breaking ore onto the compressed environment are given in Table 1.

Table 1. Basic technical and economic indicators when grilling deep boreholes.

Name	Borehole diameter:	
	105 mm	**250 mm**
Balance reserve of ore in a block, t	189000	189000
Line of least resistance, m	2.8	6.6
Distance between borehole ends, m	2.6	6.1
Total length of boreholes, m	23904	4310.4
Total explosives, kg	153737.5	124804.4
Ore yield per 1 m of borehole, t	7.9	43.8
Specific consumption of explosives, kg/t	0.81	0.66
Average piece diameter, m	0.21	0.37
Oversize, %	34.3	1.1
Labour efficiency at breaking, t/shift	314.4	581.8
Specific labour expenses (drillers), USD	1.36	0.74
Specific labour expenses (chargers and shotmen), USD	0.94	0.76
Other materials and equipment, USD	0.34	1.18
Drilling and blasting costs, USD/t	12.40	10.6

Advantages:

1. Boreholes of 250 mm in diameter increase efficiency, depth and accuracy of drilling. One 250 mm borehole corresponds to 6 – 7 bundled boreholes of 105 mm in diameter.
2. Suitable for use in weak and instable packing-averse ores.
3. No caving of hanging wall rocks

Disadvantages include the following: after drawing first portions of ore, expenses on secondary crushing of ore compacted by blasting increase; application is constrained.

The results of the conducted calculations prove that specific consumption of explosives does not differ significantly. In addition, it should be noted that the increased diameter of boreholes leads to reduction of their length from 23.9 thousand m (105 mm) to 4.3 thousand m (250 mm).

Ore breaking costs decrease from 12.4 or 12.67 to 10.6 USD/t. Thus, benefits from using boreholes of 250 mm in diameter for breaking are expected to make 1.8 USD/t. In terms of a mining block, the economic effect will make 340.2 thousand USD. With the annual output of 2.4 mln t, the annual economic effect will make 4.32 mln USD.

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Research of new methods for quality air control after massive explosions in the open mine industry

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Abstract. The aim of this study is to analyze the existing methods to determine the presence of harmful substances in the open pit atmosphere after massive explosions, and to develop a method of measuring the gas composition of the atmosphere using unmanned aerial vehicle (UAV). Existing methods of controlling the whole open pit atmosphere and its individual sections do not meet safety requirements. The main disadvantages are that workers should be present at danger zone and they are exposed at risk of poisoning by harmful gases. In addition, these methods require considerable time for delivery and analysis of samples in the laboratory, and the results contain significant measurement errors. Therefore, it is necessary to develop a methodology to determine the presence of harmful substances in the open pit atmosphere after massive explosions using UAV device, and conduct analytical research of signal dissemination to UAV control in the air. It was established that the implementation of the proposed method will allow to get quickly reliable data on the chemical composition of atmosphere in the explosion areas. It is possible to carry out the control measurements during mining operations without their interruption and without people presence in the dangerous area which allows to increase safety.

1 Introduction

Proven reserves of the iron ore for Kryvorizkyi Iron Ore Basin are one of the largest in Europe, about 32.2 billion tons, with an iron content in the ore from 22-65% [1-4]. Mining works are carried out using open and underground methods. It should be noted that minerals containing iron from 22 to 36% are exploited by open pit mining and minerals containing iron from 48 to 65% by underground mining [5-8]. Underground methods are traditionally designed using chamber system or using massive ore body collapse methods by deep wells, which reduces iron ore containing from 65% to 58-62%. It should be noted that the production cost of underground mining is much higher than open pit methods (by 2-3 times) [9-11].

To reduce production costs in underground mining works the system design is continuously improved by increasing the iron content in the mined ore mass (60-62.5) which allows to reduce the difference in the cost of production by 1.8-2.7 times [12-14].

Significant reduction in the cost of iron ore underground mining is possible by use of imported equipment and use of emulsion explosives “Ukrainit” [15-16]. To improve conditions of mining ore extraction, it is proposed to increase the diameter of the holes up to 250 mm, which significantly reduces the extraction cost. However, this enhancement will significantly worse the mine air, and with the present mechanization level, it will increase the cost of ventilation.

Thus, the open pit mining is currently providing a significant level of mechanization, productivity and economic performance, but has a negative impact on the environment, namely on the air quality.

Massive explosions in quarries are accompanied by the formation of powder-gas cloud of dust 0.030-0.19 kg/m^3, carbon monoxide - 60-95 l/kg and nitrogen oxides – 3.5-7 l/kg. Hazardous substances formed during an explosion reach high overtime concentrations in the open pit mine air. Therefore there is a negative impact on the workers and residents of adjacent areas health [17]. It should also be noted that even after required time of ventilation in the working area, blasted rock still releases toxic gases. After mass explosion, content of carbon monoxide into the blasted rock is 4-5%, and nitrogen oxides up to 0.06%. A significant danger to workers represent remaining after the explosion dust and gas, which exude from the blasted rocks and pollute the air of the blasted blocks.

Today the most common way in Kryvbas quarries to determine the presence of hazardous substances (carbon monoxide CO, carbon dioxide CO_2, methane CH_4, nitrogen oxide NO, nitrogen dioxide NO_2) and of the dust after an explosion is a measurement carried out by a group of specialized employees directly on-site. Atmosphere measurements are conducted by pumping the air through the samplers in different parts of the blasted blocks. Then air samples are delivered to a

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laboratory, which decides on the admission of workers in the explosion area [18-21].

The main drawback of this method is the presence of workers in the danger zone and therefore a risk of poisoning by harmful gases and dust. In addition, this method requires considerable time for delivery and analysis of samples in the laboratory. The results of measurements by this method unreliable because the sampling is conducted at the ground level of blasted rocks.

The method makes impossible determining of the atmosphere changes at several meters height and also during mining works, where gas emissions continue from the blasted rocks. [22-23]

Another way to control harmful substances is a method developed by Research Institute for Safety and Ecology in the Mining and Metallurgy Industries [24], it consists in the installation on a distance of 20-30 m from the blasted blocks border of hydro-mechanical and electromechanical devices for air sampling. After the explosion, under the influence of seismic waves occurs triggering of these devices. When block access is allowed, an analysis of gas concentration is conducted. Sampling takes place in special containers.

A well-known is a way of determining the presence of harmful substances, using a discrete measuring of the atmosphere chemical composition on the set trajectory around the geometric center of the blasted rocks. In the blasted blocks is installed on the ground a set of individual devices to sampling the air quality, consisting on placing them in concentric ellipsoid conventional lines (trajectories) around the geometric center of the blasted rocks. Ellipsoid lines form should take into account the direction and speed of wind [25]. Each atmosphere sampling block consists of a number of devices for sampling, which is equal to the number of sampling points accordingly to the regulations for the air quality control. Once installed, the sampling units are powered and remote controlled from a safe place. After the explosion and appearance of the gases, the device is periodically activated remotely according to adopted regulations for air quality control in the atmosphere. After the sampling, the samples from these devices are delivered to a laboratory in order to analyze the chemical composition of the atmosphere air.

The disadvantage of this method is its low reliability because there are a number of sampling units that are placed in the explosion area on the ellipsoid trajectory, therefore the devices may be damaged by pieces of blasted rock. In addition, this method is highly labor intensive and requires highly skilled and specially trained workers. During samples recovery from the devices, the workers are exposed at risk of poisoning by harmful gases and by dust. The method doesn't allow to quickly determine the changes of air chemical composition, because of the blasted rock emissions of harmful gases and dust, after the loading operations. Moreover, in case of wind direction change, the results will be distorted.

Another way to control the quality of atmosphere air, which is similar in terms of technical realization and obtained results to the one described above, is to control the atmosphere gas composition after an explosion, using unmanned aerial vehicle (UAV), which carries out a discrete measuring of the chemical composition of air in the trajectory around the geometric center from the blasted rock at some given points. UAVs are equipped with portable gas analyzer with gas and dust detectors, onboard computer, electronic altimeter and navigation. The trajectory of UAV has the form of horizontal rectangles, geometric center of which coincides with the geometric center of the blasted rocks area. A portable gas analyzer automatically saves the measurement at a preset time and transmits the obtained results to on-board computer. A signal from UAV is transmitted to the ground station computer. Using navigator, it is possible to track and record the trajectory of UAV at the fixed height from the ground which is set and controlled by an electronic altimeter [26, 27].

One of the most important characteristics is the autonomy of action and maximum range of a UAV. Compared to the other methods of control, such as direct sampling or aircraft use, the UAVs autonomy is crucial.

2 Methods

The area of mass explosions in opencast mines of Kryvbas depends on the deposit geological characteristics, for example, the width of blasted rocks area may start from 20 meters and the length starts from 200 m [26].

In this study, we consider several options for mass explosion area in order to compare the data and to identify the necessary autonomy. In addition, it is necessary to add the distance from the safe place to the work area. This distance taken from 500 m to 1000 m (in the worst case).

UAV must conduct exploration and analysis of the air after a massive explosion, its schematic trajectory of flight is shown on the Fig. 1.

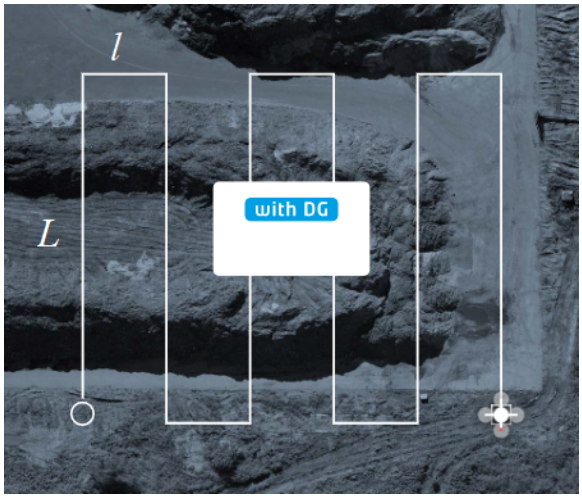

Fig. 1. Schematic trajectory of UAV movement to measure air quality after massive explosion.

For parameters of the block, we consider the block length A = 300 m and block width B = 30 m, the total length of trajectory flown over by UAV (P) is calculated

below using a pitch l = 5m.

$$P_{measures} = (A / 1 \cdot L) + (A / 1 \cdot l), \text{ m} \quad (1)$$

$$= P\,(300/5 \cdot 30) + (300/5 \cdot 5) = 2100 \text{ m} \quad (2)$$

It is also necessary to take into account the distance from the shelter to the mass explosion area, in this case $P_{shelter}$ = 2 × 1000 m = 2000 m. Generally, UAVs must travel a distance of at least 3 km in order to carry out measurements in the mass explosion area.

The velocity of the UAV will be different at each stage of trajectory, UAV velocity during the flight from shelter to work area $V_{shelter}$ will be different from the velocity during the measurements $V_{measures}$. The distance from the shelter to the work area the UAV can flight at a speed $V_{shelter}$ = 8 – 10 m/s, while for the measurement, UAV is limited to a maximum speed $V_{measures}$ at 2 – 3 m/s to ensure the measuring performance.

Thus, we get:

$$T_{total} = P_{shelter} / V_{shelter} = 2{,}100 / 8 = 263 \text{ s}, \quad (3)$$

taking 5 minutes.

$$T_{measures} = P_{measures} / V_{measures} = 1000 / 2 = 500 \text{ s}, \quad (4)$$

taking approximately 9 minutes

Thus, autonomy of UAVs must be at least 14 minutes, under ideal operating conditions (with no wind). Therefore, to choose UAVs, it is necessary to consider models with an autonomy more than 30 minutes, and with a cruising speed of 8 – 10 m/s in order to ensure reliable operations without any risk to lose the equipment. It is also necessary to consider a model with autonomous action radius of 2 – 3 km.

The career's air after a mass explosion is quite heterogeneous. Let's consider a spreading beam with a wavelength λ = 12 cm. We also consider the forces acting on dust particle as shown on the figure below (Fig. 2):

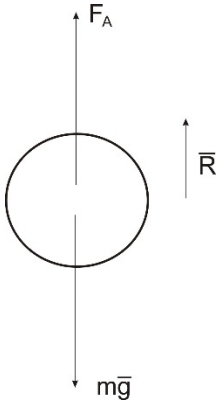

Fig. 2. The forces acting on dust particles in the air.

Power Archimedes: $F_A = M_a \cdot g$, where M_a particle mass of displaced air. The air's density is ρ_0 (kg/m^3) and to simplify we use a spherical particle with radius r. In this case:

$$F_A = \frac{4}{3} \cdot \pi \cdot r^3 \rho_0 \cdot g \quad (5)$$

R – is the resistance of air (N). According to Stokes' law:

$$R = 6 \cdot \pi \cdot \mu \cdot r \cdot U \quad (6)$$

where μ – is air's viscosity, $P_a \cdot$ s; U – is particle's velocity (m/s).

In the case of linear movement during the particle's fall if the forces are equal, we can find the velocity of dust particles fall:

$$U = \frac{2}{9} \cdot \frac{\rho - \rho_0}{\mu} \cdot r^2 \cdot g \quad (7)$$

From this expression, it follows that after the explosion, the particles with a large radius and high density fall fast. So after some time, it will remain in space the dust particles with a size which will satisfy the condition $r < \lambda$ (12 cm).

In this regard, these particles can be called "the smallest" (Fig. 3). To these particles we can apply the Rayleigh-Mie theory.

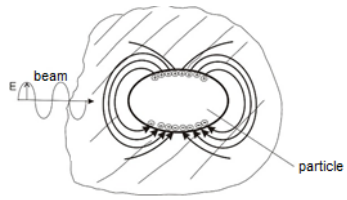

Fig. 3. The interaction of electromagnetic waves with the "smallest particle".

In this case, the functions included in the number of scattering coefficients a_N and b_N, can be expanded in power series and keep only a few firsts members:

$$\begin{cases} \Psi_1(Z) = \frac{Z^2}{3} - \frac{Z^4}{30}; \Psi'(Z) = \frac{2 \cdot Z}{3} - \frac{2 \cdot Z^3}{15}; \\ \xi_1(Z) = -\frac{i}{Z} - \frac{iZ}{2} + \frac{Z^2}{3}; \xi_1'(Z) = \frac{i}{Z^2} - \frac{i}{2} + \frac{2 \cdot Z}{3}; \\ \Psi_2(Z) = \frac{Z^3}{15}; \Psi_2'(Z) = \frac{Z^2}{5}; \\ \xi_2(Z) = -\frac{i^3}{Z^2}; \xi_2'(Z) = \frac{i}{Z^3}. \end{cases} \quad (8)$$

Using this approach, the first four amplitude coefficients are equal:

$$\begin{cases} a_1 = -\frac{i \cdot 2\alpha^3}{3} \cdot \frac{m'^2 - 1}{m'^2 + 2} - \frac{i \cdot 2\alpha^3}{5} \cdot \frac{(m'^2 - 2)(m'^2 - 1)}{(m'^2 + 2)^2} + \\ + \frac{4\alpha^6}{9} \left(\frac{m'^2 - 1}{m'^2 + 2}\right)^2; \\ b_1 = -\frac{i\alpha^5}{45}(m'^2 - 1); \\ a_2 = -\frac{i\alpha^5}{15} \cdot \frac{m'^2 - 1}{2m'^2 + 3}; \\ b_2 = 0. \end{cases} \quad (9)$$

Expansion for the amplitude scattering coefficients of higher order containing the members of order α_7 and above. If $| m' | \cdot \alpha < 1$, therefore $| b_1 | < | \alpha_1 |$

Taking this assumption, we can leave only the first partial electric wave.

$$a_1 = -i \cdot \frac{2 \cdot \alpha^3}{3} \cdot \frac{m'^2 - 1}{m'^2 + 2}. \quad (10)$$

In this case, the weakening efficiency factor will be determined by the expression:

$$Q_0 = 4\alpha Im\left\{\frac{m'^2-1}{m'^2+2} \cdot \left[1 + \frac{\alpha^2}{15}\left(\frac{m'^2-1}{m'^2+2}\right) \cdot \frac{m'^4+27m^2+38}{2m'^2+3}\right]\right\} + \frac{8}{3}\alpha\, Re^4\left(\left|\frac{m'^2-1}{m'^2+2}\right|^2\right). \quad (11)$$

To determine the scattering efficiency factor, we use the following formula:

$$Q_p = \frac{8}{3} \cdot \alpha^4 \left|\frac{m'^2-1}{m'^2+2}\right|^2. \quad (12)$$

If

$$|m'| \cdot x < 1, \quad (13)$$

$$Q_0 = 4\alpha \cdot Im\left(-\frac{m'^2-1}{m'^2+2}\right) = 4\frac{2\pi r m_0}{\lambda_0} \cdot Im\left(-\frac{m'^2-1}{m'^2+2}\right), \quad (14)$$

$$Q_p = \frac{8}{3} \cdot \frac{(2 \cdot \pi \cdot r \cdot m_0)^4}{\lambda^4} \left|\frac{m'^2-1}{m'^2+2}\right|^2. \quad (15)$$

To determine the scattering coefficients K_0 and K_p in this approach we use the following expression:

$$K_0 = \frac{6 \cdot \pi \cdot m_0}{\lambda_0} Im\left(-\frac{m'^2-1}{m'^2+2}\right), \quad (16)$$

$$K_p = \frac{4 \cdot \pi \cdot m_0}{\lambda_0} \cdot \alpha^3 \cdot \left|\frac{m'^2-1}{m'^2+2}\right|^2. \quad (17)$$

In the transition to the dielectric constant $m = n - ix$;

$$m^2 = (n^2 - x^2) - i2 \cdot \pi \cdot x = \varepsilon_1 - i\varepsilon_2, \quad (18)$$

We obtain from the following formula:

$$K_0 = \frac{6 \cdot \pi \cdot m_0}{\lambda_0} Im\left(-\frac{\varepsilon_1 - {m_0}^2 - i2 \cdot n \cdot x}{\varepsilon_1 + 2 \cdot m_0^2 - i2 \cdot n \cdot x}\right) \quad (19)$$

$$K_p = \frac{4 \cdot \pi \cdot m_0}{\lambda_0} \cdot \frac{(2 \cdot \pi \cdot r \cdot m_0)^3}{\lambda_0^3} \left|\frac{\varepsilon_1 - m_0^2 - i2nx}{\varepsilon_1 + 2m_0^2 - i2nx}\right|^2. \quad (20)$$

Thus, the problem of the remote beam spread is resolved. With a weak dependence of the complex refractive index material particles m on the wavelength λ the attenuation coefficient is: $K_0 \approx 1 / \lambda_0$, and $K_p \approx 1 / \lambda_0^4$.

The main task of the UAV is to obtain a reliable data on the atmosphere chemical composition at sites located in the area of the mass explosion. This data should include the air composition at different altitudes without people's presence and also to provide rapid control of the atmosphere chemical composition during rock loading operations [28-30].

The technical result of this proposed model allows to dramatically reduce the atmosphere control time, to obtain a reliable data after the mass explosion, and during the loading operations and exclude the participation of specially trained workers in dangerous area. Therefore, this method allows to increase a safety of workers.

According to the proposed method, measuring of the atmosphere gas composition is conducted using an unmanned UAV unit (Fig. 4), which is equipped with independent engines 1, portable gas analyzer 2, dust detectors 3, on-board computer 4, equipment to store the measurement data 5, electronic altimeter 6 and navigator 7.

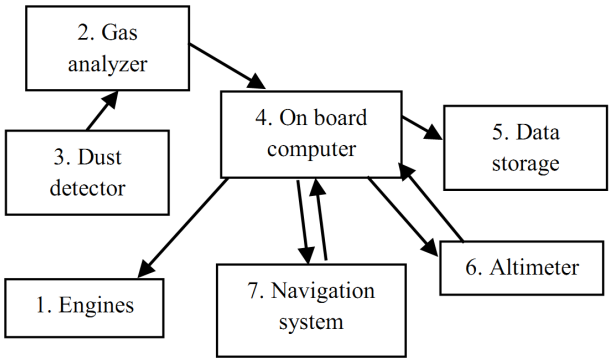

Fig. 4. Schematic diagram of the UAV (unmanned aerial vehicle).

The on-board computer generates a radio signal and transmits it to the ground computer. Movement trajectories of UAV (Fig. 5) have the form of horizontal rectangles 9, with a set of atmosphere measurement points 10. The length and width of trajectories 9 cover the entire surface of blasted rock and the geometric center 11 of the trajectories 9 which coincides with the geometric center 12 of the blasted rock.

The parameters of smaller concentric rectangular trajectories 13 are determined based on the adopted regulations to control the atmosphere. The UAV movement trajectories 9 include the different heights H_1, H_2, H_3 from the surface.

To ensure reliable measurements of particles, the UAV is equipped with additional camera by which is conducted aerial photographing during the gas composition measuring.

The calculation of the harmful substances concentration at massive explosion is carried out by the authors [31, 32], it allows to conclude that the concentration of carbon monoxide, nitrogen oxides and dust in the atmosphere exceeds the maximum permitted level. This creates a critical situation because of air pollution in the working area.

The intensity of air pollution depends on the properties and state of the rock, weather conditions, equipment and technology, efficacy of methods of dust and harmful gases control.

In this regard, the level of dust and of air pollution in the workplace may vary widely. Significant impact on career's air quality has the composition and moving direction of air flows, which in many cases determines the amount of contaminants. To solve this problem, it has been proposed a method to control by the UAV the gas composition in carrier's atmosphere after mass explosion.

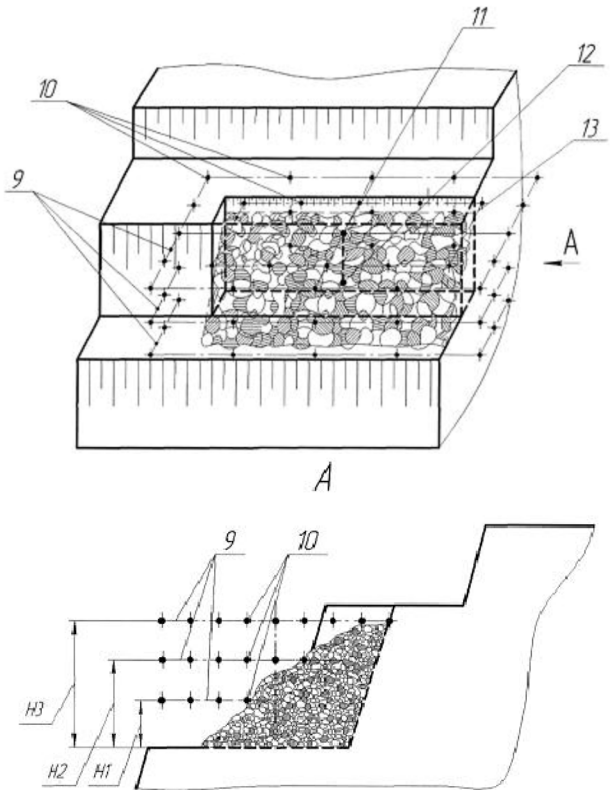

Fig. 5. UAV movement trajectory [26].

3 Results and discussion

Implementation of the proposed method to control the career's atmosphere after the mass explosion will allow to quickly obtain a reliable data on the air chemical composition in mass explosion areas without people's presence, and without interruption of mining operations.

This method to control the career's atmosphere and the gas composition after mass explosion, including discrete measurements of chemical composition on the trajectory around the geometric center of the blasted rock at given points, consists by measurement of gas composition using UAV, whose is equipped by a portable gas analyzer with gases and dust detectors, an on-board computer, an electronic altimeter and a navigation. UAV trajectory has the form of horizontal rectangles, which geometry center coincides with the geometric center of the blasted rock area. UAV use a portable gas analyzer which automatically saves the current measurement at preset time, with the transmission of the obtained results from on-board computer.

Measurements of the atmosphere chemical composition are done at the different heights from the surface. UAV is equipped with additional cameras by which is conducted an aerial photographing during the measuring of the atmosphere gas composition; the measurements data is compared to the coordinates at given points during UAV's flight path.

Thus, the use of UAV for determining the concentration of harmful gases after massive explosions allows to avoid the human presence in the dangerous area and to obtain quickly the information about air quality (the total time to collect and process the information would not exceed 1 hour). The disadvantages of the method is the relatively high cost of the equipment.

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Identification of the process of hydromechanical extraction of amber

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Abstract. The article deals with the method of hydromechanical extraction of amber from sand deposits. The essence of hydromechanical method of amber extraction is considered. The process of extraction has been identified. The analytical expressions obtained for calculating the parameters of hydromechanical extraction of amber from sand deposits, and in particular the expression for determining the rate of emergence of an amber particle, can be used in the further engineering calculations of process parameters and process equipment. These expressions will allow to accurately substitute and with sufficient accuracy to calculate the parameters of the process of extracting amber from amber-containing deposits, as well as to set the parameters of technological equipment for the implementation of this process.

1 Introduction

The essence of the above method is that the array is saturated with water and activated by mechanical excitation to form a continuous slurry of such density at which there is an ejection force that raises the amber on the surface of the deposit. Mechanical action, when present in an array of water, causes the array to completely lose the bond between the particles, release the amber and reach a suspension state with a density greater than the specific gravity of the amber, which allows the latter to float to the surface of the field at the expense of the field.

To implement the method, it is necessary to dip the rods in the amber array in the form of pipes from which water and air are supplied and on which mechanical exciters are fixed. The array is saturated with water and the working body is oscillated. Amber is released from the environment and floats to the surface [1].

The process of soil liquefaction is as follows. In the amber array vibrating method immerses rods with biconical vibrators while simultaneously feeding water and air into the soil array through them. The array of vibrators is oscillated, thus forming a zone of continuous boiling of the soil. Amber separates itself from the massif and under the action of ejection force floats to the surface. The suspension medium allows the vibration device to move freely in the longitudinal direction.

The use of vibrating gear for the extraction of amber from the fields allows achieving the extraction of amber from the field, increasing labor productivity and reducing energy intensity and negative man-made environmental impact on the environment [2].

To increase production volumes while reducing cost, the industry requires the introduction of advanced technologies in amber production. In the absence of financing in this sector, investments from the state are absent. Amber mining is an outdated method that requires a great deal of money and time to extract and process large amounts of soil to produce amber. Figure 1 shows a diagram of one of the largest amber fields in Ukraine.

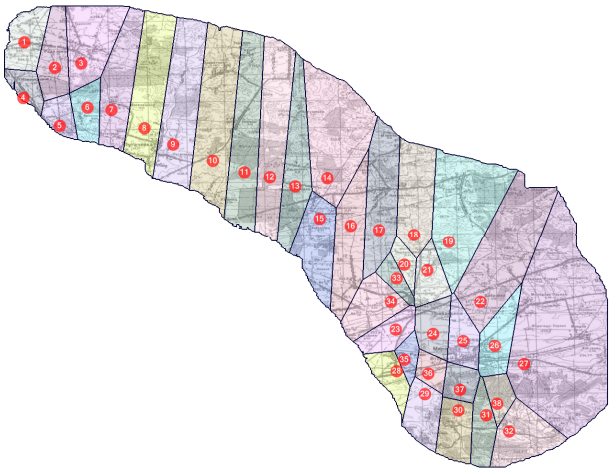

Fig. 1. Klesiv amber deposits.

Thus, today, amber production requires new technologies and the development of means to intensify the extraction process, which achieves high productivity and efficiency, and also reduces the negative environmental impact on the environment [3-9].

2 Methods

The northern regions of the Rivne region are characterized mainly by the occurrence of amber in sandy soils, characterized by water and air pores present

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between the soil skeleton. between them, the Sandy soil moves into a mobile state when the equilibrium between the soil skeleton and the water pores is disturbed, and the slight influence of the hydraulic flows can cause the mass to shift and the considerable mass of the soil to a liquefied state. The transition of water-saturated sands to the liquefied state causes destruction of the structure of the sands and their compaction under the influence of their own weight or external influences. When the sand is thinned, the bearing capacity is lost completely or partially, and the fluid state arises as a result of the destruction of the structure and displacement of the sand particles relative to each other, which is accompanied by the formation of a denser particle arrangement and a decrease in porosity.

The liquefaction phenomenon occurs when the structure and possibility of sand compaction are destroyed; full or close to full saturation of sand with water.

In the course of research, the amber sand deposit at the initial stage enters the state of vacuum, and in the subsequent there is its compaction. The duration of water saturated sands in the rarefied state is much shorter than the time of soil compaction. In our opinion, and based on the results of the analysis of literature sources, the compaction process is more investigated than the liquefaction process, so experimental studies of the liquefaction process, the flow of the process of reaching the surface of amber and the time of transition of sandy soil to the compacted state require additional research. In order to create the necessary conditions to reach the surface of the amber, it is necessary to investigate the parameters of vibrational impact and the use of water and air when exposed to a sandy field.

In conducting experimental studies, we studied the environment of amber, while simulating the boiling process and conducted research on the factors and parameters that affect the creation of the suspension environment.

Studies have shown that the liquefaction structure destroys the sandy amber medium. The sand particles, within the vibration range, are separated from the total array and are brought into oscillatory motion near their equilibrium position and are also moved along some trajectory relative to the vibration source. At the same time there is an intensive movement of gas and water, which take with them sand particles and amber and throw them on the surface. Since the surface of the amber significantly exceeds the area of the particles, under the action of Archimedes force pieces of amber are pushed to the surface.

The following stages of transformation are observed during the vibrational action on a sandy soil mass [2]:
- vibration dilution (maximum preparation for intensive mixing);
- vibration boiling (separation of particles and mixing in the array);
- gradual compaction of the sandy soil mass from the periphery to the vibration source.

The effect of the thinning of the layer is similar to the phenomenon of vibration linearization of dry friction, that is, in the presence of vibration to transfer a particle of relative motion in the environment requires less constant force than in its absence. As the effective coefficient of friction decreases in the vibration state, the particles slip away relative to one another. The spreading layer is compacted.

From studies [4-8] it is known that the movement of sand in a vibrating fluid bed is not subject to the law of motion of particles in airless space. In addition to gravity, the trajectory of movement of the sand layer is significantly influenced by the parameters of the environment. Throwing produces a rarefaction, while falling - increasing the pressure of the environment. The lower layers of sandy soil have a greater pressure drop than the upper ones, so the air is displaced from below and seals between the particles.

In this way, the vibrating fluidized bed of sandy soil behaves like a pump that pumps a gas-liquid mixture to the surface, taking particles of amber and transporting them to the top. In this case, the rate of rise of the particle from bottom to top depends on the vibrational excitation of the array, the dilution of the medium, saturation with air bubbles and the viscosity of the medium.

The pressure drop depends on the frequency and amplitude of the oscillator, the height of the layer, the particle size and humidity of the sandy soil, as well as the coefficient of friction of the particles one by one. The intensity of the pumping action of the vibrating boiling layer is characterized by three parameters: pressure above and rarefaction under the vibrating boiling layer, pressure drop in the layer.

The following parameters influence the creation of a vibrating fluid layer of soil: 1) oscillation amplitude; 2) oscillation frequency; 3) compelling force; 4) water pressure; 5) air pressure; 6) geometric arrangement of the oscillators.

To a large extent, these parameters are experimentally determined.

Submission into the sand mass of air together with water can intensify the process of lifting the amber to maximum values, but when the air trunks are formed, the boiling process goes into vibration and stops. The maximum rate of flow of amber to the day surface is observed when changing the flow of gas-liquid mixture in the sand array in the range 0 to 0,02 m^3/h.

Creating the desired density of the medium depends on the flow of gas-liquid mixture into the array.

Figure 2 shows the results of experimental studies of the simultaneous influence of the oscillation frequency of the working body and the magnitude of the air flow into the sand array, which demonstrate the explicit manifestation of two peak areas of maximum amber flow velocities [10].

On the basis of the obtained experimental dependence, we have the following ranges of values of the oscillation frequency of the working body and the magnitude of the air flow into the amber-containing array: the oscillation frequency of the working body 28-34 Hz; the magnitude of the air flow into the array 0,003-0,006 m^3/h, with the speed of lifting amber is the highest and is 0,09-0,12 m/s [10].

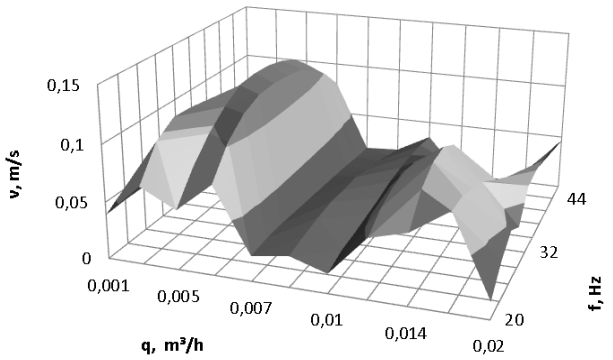

Fig. 2. Dependence of the amber rise rate on the frequency of oscillation and the supply of air to the water-saturated array.

3 Results and discussion

3.1 Analysis of models of motion of an amber particle under hydromechanical action

The movement of amber in a sandy massif is characterized by movement with resistance to the type of dry friction. The movement of a particle placed in a medium that performs horizontal oscillations with frequency and radius of the trajectory and produces a particle resistance similar to dry friction. The corresponding problem was considered by V. V. Gortinsky, G. E. Ptushkin and I. I. Blechmann [11]. Here are the main results of the solution and their discussion in terms of hydromechanical amber production. These authors have considered the following system of differential equations of motion of a particle with respect to the medium to determine the rate of emergence of amber

$$m_1\ddot{x} = m_0(\Delta - 1)rf^2\cos ft - F_h\frac{\dot{x}}{\sqrt{\dot{x}^2+\dot{y}^2+\dot{z}^2}}, \quad (1)$$

$$m_1\ddot{y} = m_0(\Delta - 1)rf^2\cos ft - F_h\frac{\dot{y}}{\sqrt{\dot{x}^2+\dot{y}^2+\dot{z}^2}}, \quad (2)$$

$$m_1\ddot{z} = m_0(\Delta - 1)g - F_v\frac{\dot{z}}{\sqrt{\dot{x}^2+\dot{y}^2+\dot{z}^2}}, \quad (3)$$

$$\Delta = \rho / \rho_0, \quad (4)$$

$$\sqrt{\dot{x}^2+\dot{y}^2+\dot{z}^2} \neq 0. \quad (5)$$

where F_v – the force of resistance to the relative displacement of the particle in the vertical direction, N;
m_1 – the mass of the particle taking into account the attached mass of the medium, kg;
m_0 – mass of the medium in volume equal to the volume of the particle, kg;
$\dot{x}, \dot{y}, \dot{z}$ – projections on the axis of the rectangular coordinate system XYZ of the relative velocity of the particle in the medium, m.

This allowed them to propose the following dependence for determining the rate of emergence of amber [12]:

$$v = \frac{a^2}{\sqrt{\left(\frac{F}{gm}\right)^2 - a^2}}\frac{\alpha}{k_m}, \quad (6)$$

$$\alpha = \begin{cases} Af, & A^2 f < kg \\ \frac{kg}{f}, & A^2 f > kg \end{cases}, \quad (7)$$

$$a = \rho - 1, \quad (8)$$

$$\rho = \frac{\rho_c}{\rho_s}, \quad (9)$$

where v – the rate of emergence of the amber particles, m/s;
m – weight of amber particles, kg;
a – the Archimedes parameter for the amber particle;
g – free fall acceleration, m/s^2;
k_m – the coefficient of the coupled mass;
f – frequency of oscillation of the working body, Hz;
F – the force of resistance of the sand layer relative to the motion of the amber particle [12];
ρ_s – density of amber particles, kg/m^3;
ρ_c – density of water-sandy environment, kg/m^3;
A – oscillation amplitude of the working body, m;
k – coefficient of friction.

Formula (6) is obtained for the case of particle flooding of lower density in the layer of particles of heavier material when the oscillation of the working body in the plane of the surrounding medium [13-17]. In this case, the authors assume that apart from the forces of inertia, Archimedes, and gravity, only the forces of resistance to relative motion are active, and the trajectory of motion of the particle is a spiral.

However, there are no recommendations for determining the magnitude of the force for the conditions under consideration. Given the dimension and nature of this magnitude, as well as the fact that it characterizes the interaction between the amber particle and the soil skeletal particles, the following option is proposed to determine the magnitude of this force

$$\frac{F}{gm} = \phi(1+a), \quad (10)$$

where ϕ – the drag coefficient of the sand medium of the amber particle motion [18].

Substituting the dependence (10) into formula (6), the following expression is obtained for the rate of emergence of an amber particle:

$$\frac{k_m v}{\alpha} = \frac{a^2}{\sqrt{\phi^2(1+a)^2 - a^2}}. \quad (11)$$

The obtained formula (11) takes into account the influence of the difference in the density of the soil particles and the extracted material, as well as the amplitude and frequency of oscillation of the working body. The effect of the air supply is only taken into account by changing the density of the amber-containing medium.

To determine the magnitude of the coefficient ϕ we will use the results of experimental studies by well-known authors on the emergence of amber particles in laboratory and field conditions [19-29]. In this case, expression (11) will have a more convenient definition for ϕ:

$$\varphi = \sqrt{1+\frac{\alpha}{k_m v}}\left(1-\frac{\rho_s}{\rho_c}\right). \quad (12)$$

From the received data it is visible that for the whole interval of the studied values at calculations with engineering accuracy it is possible to use the average value of the coefficient ϕ equal to

$$\phi = 0{,}325. \quad (13)$$

It follows from formulas (6) - (13) that in hydromechanical extraction of amber from sand deposits, the ratio of the force that impedes the movement of the particle in the bulk medium to the volume of the particle, the density of the medium and the acceleration of free fall is equal to 0,325.

The results of the study of expression (11) on the extreme indicate that this function has a maximum at a point:

$$a_{\max} = \frac{3}{2}\frac{\phi^2}{1-\phi^2}\left[1+\sqrt{1+\frac{8}{9}\frac{1-\phi^2}{\phi^2}}\right], \quad (14)$$

the coordinate of which at $\phi = 0{,}325$ is $a_{\max} = 0{,}6946$.

Thus, it is necessary to consider the motion of the amber particle in the vertical direction, taking into account Archimedes force, vibrations of the working body, as well as the forces of relative resistance of the medium and viscous friction [30-36]. In this case, given the results already obtained and the assumption that the positive direction of the coordinate axis is directed vertically upwards, the equation of motion of the floating particles can be written as follows:

$$\left(1+k_m\right)m\frac{d^2z}{dt^2} = m_0 ga + m_0 Sf^2 \sin ft - F - F_c, \quad (15)$$

$$m = \rho_s \frac{\pi d^3}{6}, \quad (16)$$

$$m_0 = \frac{\rho_c}{\rho_s} m, \quad (17)$$

$$F = \phi m_0 ga, \quad (18)$$

$$F_c = C_x \rho_c \frac{v^2}{2}\frac{\pi d^2}{4}, \quad (19)$$

where z – moving particles of amber, m;
t – time, s;
m_0 – weight of amber-containing sand in the volume of amber particles, kg;
S – the oscillation amplitude of the working body, m;
F_c – the force of viscous friction of an amber particle when moving through a liquefied medium, N;
d – diameter of amber particles, m;
C_x – force coefficient of viscous resistance.

Taking into account recommendations [37-49], we assume that the Stokes regime of the flow of amber particles when moving through a liquefied fluidized medium, for which according to [29] the dependence of the coefficient of viscous drag force on the Reynolds number can be distinguished as follows:

$$C_x = \frac{26}{\mathrm{Re}_c}, \quad (20)$$

$$\mathrm{Re}_c = \frac{vd}{\nu_c}, \quad (21)$$

where Re_c – Reynolds number characterizing the process of interaction of the amber particle with the liquefied medium;
ν_c – kinematic viscosity of the liquefied medium.

Substituting formulas (16) - (21) into equation (15) and having the corresponding transformations, we obtain the following equation of motion of an amber particle through a liquefied medium

$$\frac{d^2\zeta}{d\tau^2} + f_0^2\frac{d\zeta}{d\tau} = A_0\frac{\rho-1}{\rho} + A\sin a\tau, \quad (22)$$

$$\zeta = \frac{z}{d}, \quad (23)$$

$$\tau = \frac{gd}{\nu_g}t, \quad (24)$$

$$f_0 = \sqrt{\frac{39\sigma}{2\left(1+k_m\right)\rho Gm}}, \quad (25)$$

$$A_0 = \frac{\left(1-f\right)}{\left(1+k_m\right)\rho Gm}, \quad (26)$$

$$A = \frac{a^2}{\left(1+k_m\right)\rho}\frac{S}{d}, \quad (27)$$

$$a = \frac{\omega\nu_g}{gd}, \quad (28)$$

$$Gm = \frac{gd^3}{\nu_g^2}, \quad (29)$$

$$\sigma = \frac{\nu_c}{\nu_g}, \quad (30)$$

$$\rho = \frac{\rho_c}{\rho_s}, \quad (31)$$

where σ – the viscosity ratio of the liquefied medium [10];
ρ – the relative density of the liquefied medium;
ν_g – kinematic coefficient of air viscosity.

The solution of equation (22) is investigated and reported in the specialized literature, and it is proved that the periodic term, when averaging, makes no significant

contribution compared to the stationary component [15]. Thus, the amber medium can be considered as a liquefied layer when the hydromechanical action disrupts the contact between the amber particles and the particles of the array, between the particles of the amber-containing array, but does not directly affect the movement of the amber particles. The effect is to increase the mobility of the particles and the porosity of the array, to reduce the friction between the particles, as well as to obtain an array of viscosities similar to the kinematic viscosity of a liquid substance [29]. That is, the hydromechanical effect creates favorable conditions for the work of Archimedes force, which ensures that the particles of amber float to the surface.

In this case, the equation of motion of the amber particle with hydromechanical action on the amber-containing layer takes the following form

$$v = \frac{2(1-f)}{39}\frac{gd^2}{\sigma\nu_g}\frac{\rho-1}{\rho}. \quad (32)$$

Given the ratio of the density of the flooded soil to the air, the relative density of the liquefied medium can be determined by the following formula:

$$\rho = (1-\varepsilon)\Delta, \quad (33)$$

$$\Delta = \frac{\rho_0}{\rho_s}, \quad (34)$$

where ε – the porosity of the liquefied medium;
Δ – the ratio of the particle densities of the water-saturated soil to the soil and amber.

The results of experimental studies on the measurement of the density of a layer of water-saturated soil containing particles of amber under hydromechanical exposure with and without air supply show that the porosity of the medium under the considered influence on the soil mass with engineering accuracy can be determined.

At the same time, formulas (32) - (34) should describe the dependence of the flow rate of the amber particles on the air flow, with a characteristic maximum in the neighborhood of q = 0,015 m^3/h. Substituting expression (33) into formula (32), it is easy to obtain an expression for the first derivative of q:

$$\frac{dv}{dq} = -\frac{\beta+2\alpha q}{(1-\varepsilon)^2}\frac{2(1-f)}{39\Delta\sigma}\varepsilon_\omega\frac{gd^2}{\nu_g}. \quad (35)$$

It can be seen from formula (35) that the dependence (32) on the variable q is decreasing over the entire interval and has no extremes. This means that in order to adequately describe the processes under consideration, it is necessary to take into account the change in not only the density but also the effective viscosity of the liquefied medium. Similar processes are realized in the processing of bulk material in vibrating, boiling and pulsating fluidized layers [12-24]. The results of the analysis of known mathematical models describing hydrodynamic processes in such layers with steady or pulsed air supply suggest two types of formulas for calculating the dynamic viscosity coefficient of the liquid medium under consideration [29].

The first group of formulas, to which Einstein's dependencies [15], Vakhrushev, Gupalo, Kunitz, and Todesa [29] include, depend on the degree of porosity without taking into account the influence of other factors:

$$\sigma = \frac{M}{\varepsilon^N}. \quad (36)$$

However, the authors do not indicate what determines the values of the coefficients in formula (36), how to choose them, and how to consider other factors, such as the volume air flow, the size and density of soil particles. The formulas of the second group [15] take these factors more fully into account, which complicates the calculated dependencies and requires their adaptation to the conditions of use.

The maximum effect of these parameters is taken into account in determining the dynamic viscosity of the liquefied medium by the following method [29]:

$$\mu = 0,7282\frac{g^{1,207}\delta^{2,207}\rho_g^{0,707}}{(v_g-v_0)^{1,414}}\rho_0^{0,293}\sqrt{1-\varepsilon}, \quad (37)$$

$$v_0 = \frac{v_g}{4,9}\left(\frac{\rho_0}{\rho_g}\right)^{0,1}, \quad (38)$$

where μ – the dynamic viscosity of the liquefied medium;
δ – diameter of particles of soil skeleton containing amber, m;
ρ_g – air density, kg/m^3;
ρ_0 – density of water saturated amber medium, kg/m^3;
v_g – air speed, m/s;
v_0 – the sliding velocity of particles of amber-containing medium, m/s.

Substituting expression (37) into formula (38), moving from a dynamic coefficient of viscosity to a kinematic coefficient of viscosity, conducting the corresponding transformations and transition to dimensionless quantities, taking into account formula (34), after approximating the dependence of the coefficient of proportionality on the ratio of the density ratio and air by a power function, we obtain the following expression for calculating the magnitude σ:

$$\sigma = k_v\frac{Gm^{1,207}}{\rho\,\mathrm{Re}_g^{1,414}}\sqrt{1-\varepsilon}, \quad (39)$$

$$k_v = 0,6898\Delta^{0,407}\left(\frac{\rho_g}{\rho_s}\right)^{0,593}, \quad (40)$$

$$\mathrm{Re}_g = \frac{v_g\delta}{\nu_g}, \quad (41)$$

$$Gm = \frac{g\delta^3}{\nu_g^2}, \quad (42)$$

where Re_g – Reynolds number characterizing the process of interaction of the particles of the liquefied medium with the incoming air;
Gm – dimensionless complex.

The Reynolds number characterizing the process of formula (44) includes the characteristic air velocity, for which it is recommended to use the following dependences when considering the processes occurring in the layer [15]:

$$\tilde{q} = v_g F_g \varepsilon_u , \quad (43)$$

$$\varepsilon_u = 1,2\varepsilon_* \left(\frac{v}{v_*} \right)^{\theta} , \quad (44)$$

$$\theta = 0,08 + 4 \cdot 10^{-8} a_0 Gm , \quad (45)$$

$$a_0 = \frac{\rho_0 - \rho_g}{\rho_g} , \quad (46)$$

where $\tilde{q}$ – volume flow rate of air supplied to the soil, m^3/s;
F_g – the characteristic area on which the air from the nozzle head liquefies the soil layer, m^2;
ε_u – effective porosity of the soil layer;
ε_* – effective porosity of the soil layer at the initial moment of liquefaction;
v_* – air velocity, providing the beginning of liquefaction, m/s;
θ – exponent;
a_0 – the Archimedes parameter for an amber-containing soil particle in the air supply.

The results of the calculations performed by the formula (45) show that the values of the density and particle size of the skeleton of the sandy-clay mixture under study, without losing the accuracy of the value of the exponent θ can be considered equal 0,08.

Based on this, using the results of experimental studies on the measurement of the density of the soil layer containing particles of amber under hydromechanical action with and without air supply, the dependence (44) can be rewritten as follows:

$$\varepsilon_u = \varepsilon_\omega \left(\frac{\tilde{q}}{\tilde{q}_\omega} \right)^{0,08} , \quad (47)$$

where $\tilde{q}_\omega$ – characteristic air supply, $\tilde{q}_\omega = 0,000217$.

To estimate the characteristic area on which the air from the nozzle head liquefies the soil layer, we will use recommendations for choosing the geometric parameters of the probe used for direct impact on the soil, in particular, the estimate of the distance between adjacent rods [10, 15, 24, 29]. Assuming that the air exiting the nozzle liquefies the soil to a volume limited by two axial cylinders. The outer cylinder radius is equal to this value and the inner cylinder radius is equal to the radius of the bar. In this case, the value F_g can be determined from the following formula [15]:

$$F_g = \pi tg\phi \left(\frac{d_T}{h_{dd}} + tg\phi \right) h_{dd}^2 , \quad (48)$$

where ϕ – the taper angle of the nozzle through which air is supplied;
d_T – the diameter of the bar on which the attachment is attached, m;
h_{dd} – length of the conical part of the working body, m.

Substituting formulas (44) - (48) into expression (43), after performing all the transformations taking into account (39) - (43), we obtain the following dependencies for determining the value σ:

$$\sigma = k_\sigma \frac{\sqrt{1-\varepsilon}}{\rho z^{1,3}} , \quad (49)$$

$$k_\sigma = K \left(\frac{\rho_g}{\rho_s} \right)^{0,593} Gm^{0,735} \Delta^{0,407} \frac{\varepsilon_\omega^{1,414}}{1,45} , \quad (50)$$

$$K = \left(\frac{\sqrt[3]{g v_g} h_{dd}^2}{1,37 \tilde{q}_\omega} \right)^{1,414} , \quad (51)$$

$$z = \frac{\tilde{q}}{\tilde{q}_\omega} , \quad (52)$$

where *K* – dimensionless technological constant;
z – dimensionless air flow.

Thus, a joint consideration of formulas (32) - (34), (10), (11) and (49) - (52) gives us the following dependencies for determining the rate of emergence of an amber particle under hydromechanical action on a water-sandy massif:

$$\mathrm{Re} = \frac{w}{\Delta^{0,407} \varepsilon_\omega^{1,414}} \frac{(1-\varepsilon)\Delta - 1}{\sqrt{1-\varepsilon}} z^{1,3} , \quad (53)$$

$$\mathrm{Re} = \frac{vd}{v_g} , \quad (54)$$

$$w = \frac{1-f}{13,45K} \left(\frac{\rho_s}{\rho_g} \right)^{0,593} \left(\frac{d}{\delta} \right)^3 Gm^{0,265} , \quad (55)$$

where Re – Reynolds number, which characterizes the process of the emergence of amber particles through a vibrating pneumatic fluid medium.

It is convenient to rewrite the right part of expression (53) in the following form, bringing the two terms in the numerator and denominator to the same form

$$\frac{\mathrm{Re}}{W} = \frac{1 - n\varepsilon}{\sqrt{1-\varepsilon}} z^{1,3} , \quad (56)$$

$$W = w \frac{\Delta - 1}{2,2\Delta^{0,407} \varepsilon_\omega^{1,414}} , \quad (57)$$

$$n = \frac{\Delta}{\Delta - 1} . \quad (58)$$

Given that the value of soil porosity in hydromechanical impact is subject to the following restriction from above

$$\varepsilon < 1 , \quad (59)$$

then, based on the rules of representation of functions of this kind in power series, the dependence (56) can be rewritten as follows (Fig. 3): then, based on the rules of representation of functions of this kind in power series, the dependence (56) can be rewritten as follows (Fig. 3):

$$U = \left(1 - \left[\gamma + \beta z + \alpha z^2\right]\varepsilon_\omega\right)^m z^{1,3}, \qquad (60)$$

$$U = \frac{\mathrm{Re}}{W}, \qquad (61)$$

$$m = \frac{1}{2}\frac{\Delta+1}{\Delta-1}. \qquad (62)$$

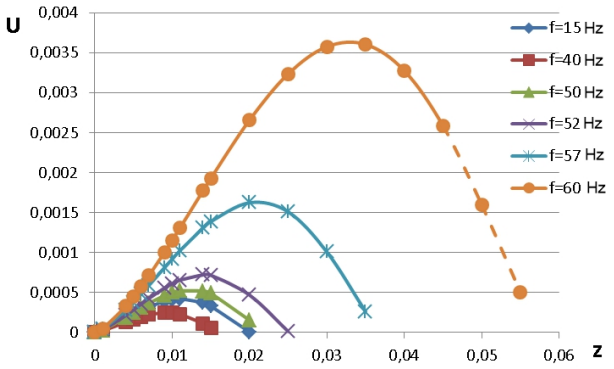

Fig. 3. Dependency graphs *U* from dimensionless air flow at different oscillations of the working body.

From Fig. 3 it is seen that the obtained dependence of the dimensionless velocity of the particles of amber on the dimensionless flow rate (60) has a maximum in the range of values of air flow close to the experimentally obtained value, in the vicinity q = 0,015 m^3/h, which depends on the frequency of oscillation of the working body, similar to the results obtained in laboratory and field experiments [29].

Comparison of the results of the formulas (60) made for the frequency of 30 Hz with the results of experimental laboratory studies shows a satisfactory coincidence of the results of the calculations and experiments in the area q = 0,015 m^3/h (Figs. 4, 5). Thus, in the volume flow rate range from 0,014 to 0,025 m^3/h, the relative error of calculations does not exceed 10%.

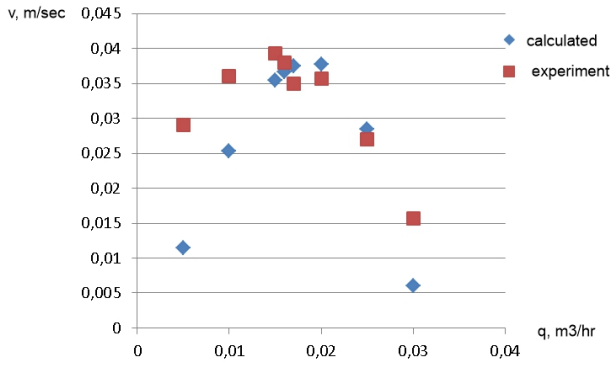

Fig. 4. Dependence of the amber particle floating rate on the air volume supplied at a 30 Hz oscillator.

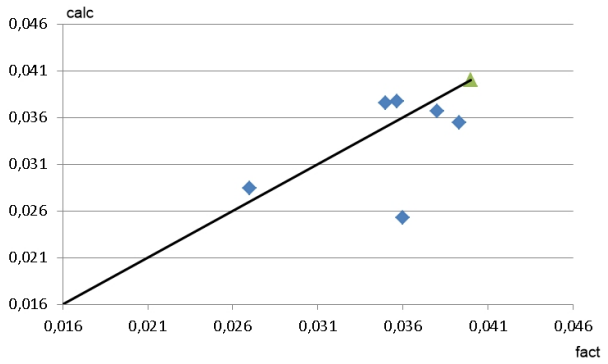

Fig. 5. Comparison of the results of calculations and experiments at the oscillation frequency of the working body of 30 Hz (error of calculations does not exceed 10%).

3.2 Determination of the rational parameters of the process of hydromechanical extraction of amber from sand deposits

The study of the dependence (60) on the extreme, by approximating the first derivative in magnitude to zero, indicates the existence of a maximum of the function under study at the following value of dimensionless air flow:

$$z_{\max} = \sqrt{A^2\left(\frac{\beta}{2\alpha}\right)^2 + B\frac{1-\varepsilon_\omega\gamma}{\varepsilon_\omega\alpha}} - A\frac{\beta}{2\alpha}, \qquad (63)$$

$$A = \frac{1{,}3\Delta - 0{,}8}{2{,}3\Delta - 0{,}3}, \qquad (64)$$

$$B = \frac{1{,}3(\Delta-1)}{2{,}3\Delta - 0{,}3}, \qquad (65)$$

where $z_{\max}$ is the value of dimensionless air flow at which the maximum velocity of the particles of amber is realized.

Substituting expression (63) into formula (60) and performing the corresponding transformations and erections of such terms, we obtain the following dependence for determining the maximum rate of emergence of amber particles under hydromechanical action on the water-sandy massif:

$$\mathrm{Re}_{\max} = W_\Delta\left(z_\omega - z_{\max}\right)^m z_{\max}^{1,3}, \qquad (66)$$

$$z_\omega = \frac{1-\gamma\varepsilon_\omega}{\varepsilon_\omega\beta}\frac{\Delta+1}{\Delta+0{,}5}, \qquad (67)$$

$$W_\Delta = w\frac{\Delta-1}{\Delta^{0{,}407}}\left(\frac{\Delta+0{,}5}{2{,}3\Delta-0{,}3}\right)^m \varepsilon_\omega^{m-1{,}414}\beta^m. \qquad (68)$$

Comparison of the results of formulas (63) and (66) performed for the frequency of 30 Hz with the results of experimental laboratory studies shows sufficient accuracy for engineering calculations and: relative error for air flow does not exceed 11,3% (calculation – 0,0133 and fact – 0,015 m^3/year); and for the maximum velocity of the particles of amber is 32,5% (the calculation is 0,053 and the fact is 0,04 m/s). The high error in

determining the maximum floating velocity can be explained by the significant dependence of this value on the particle size of the amber and the skeleton of the water-saturated soil, which varied during the experimental studies at fairly wide intervals.

Comparison of the results of the calculations according to formula (63) with the results of other authors [2-9, 15, 17-29] (Figs. 6, 7) confirms the reliability of the proposed dependence obtained for laboratory studies at a frequency of 30 Hz (Fig. 8, 9).

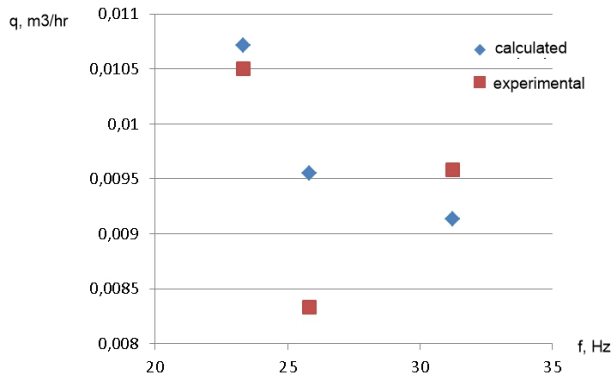

Fig. 6. The dependence of the air flow rate, which provides the maximum flow rate of the amber particles obtained by calculation (63) and according to experiments, from the frequency of oscillation of the working body.

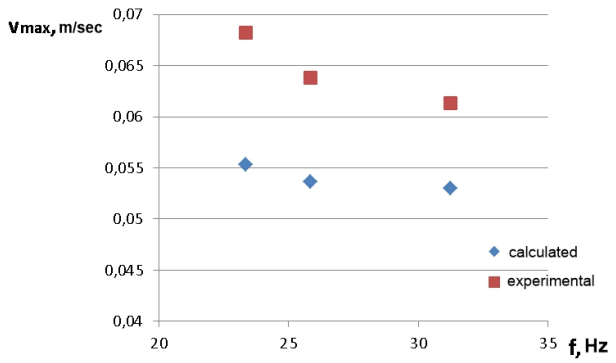

Fig. 7. The dependence of the maximum rate of emergence of amber particles obtained by calculation (63) and according to experiments, on the frequency of oscillation of the working body.

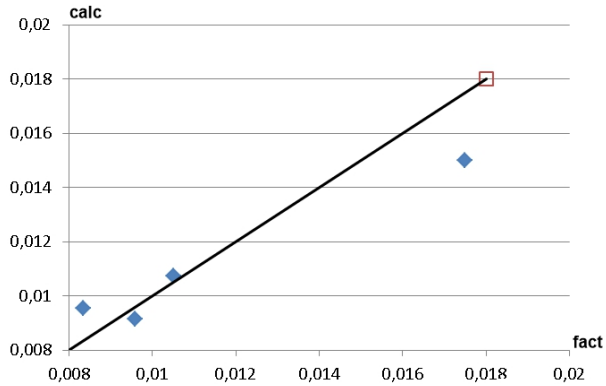

Fig. 8. Comparison of the results of the calculations by (63) and the experiments to determine the air flow rate, which provides the maximum velocity of amber particles (relative error does not exceed 11,3%).

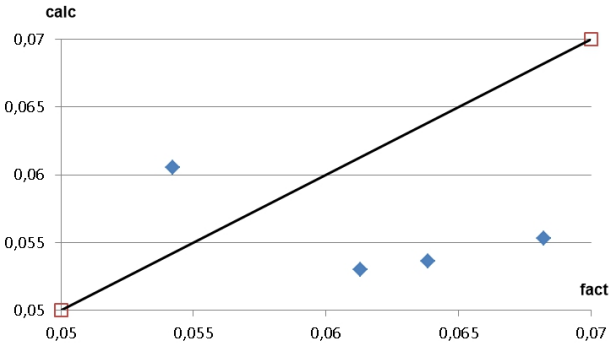

Fig. 9. Comparison of the results of the calculations for (63) and experiments to determine the maximum rate of emergence of amber particles.

The results of the numerical analysis of the terms on the right-hand side of formula (63) indicate that it is possible to use for engineering calculations the air flow rate, which provides the maximum velocity of the particles of amber, the following simplified dependence:

$$z_{\max} = 0,008\frac{\Delta^{0,281}}{\sqrt{\varepsilon_\omega}}. \qquad (69)$$

Joint consideration of formulas (66) - (69), with preliminary approximation of complexes depending on the value Δ degree functions, allows you to propose the following simplified dependence for engineering calculations of the maximum velocity of the particles of amber floating:

$$\mathrm{Re}_{\max} = \frac{w\gamma^m}{500}\frac{\Delta^{1,86}}{\varepsilon_\omega^{2,064}}. \qquad (70)$$

Conclusions

Studies have shown that the maximum possible rate of emergence of amber in hydromechanical extraction of sand deposits is directly proportional to the square of the diameter of the particles of amber and the medium, and inversely proportional to the square of the porosity of the soil, which arises from the oscillation of the working organ 20 to 35 Hz without air supply, and its dependence on the density ratio of the soil particles and the material extracted is described by a power function with a positive fractional index of 1,86.

The analytical results obtained confirm the experimental data quite accurately, which allows us to use them in the future for engineering calculations. The obtained expressions will allow with sufficient accuracy to calculate the parameters of the process of extracting amber from amber-containing deposits, as well as to set the parameters of technological equipment for the implementation of this process.

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Method for optimizing the protecting pillars parameters in underground coal mining

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Abstract. A method for optimizing the protecting pillars parameters during the study of soft enclosing rocks (in Ukraine mines) is represented. The necessity of a differentiated approach has been substantiated when choosing the protecting pillar parameters based on the geomechanical factors analysis influencing the state of massif. Mining and geological situation was analysed. It has been studied a stress-strain state (SSS) along the protecting pillar width with account of the mined-out space on the basis of a computational experiment and is presented in the form of curves of vertical and horizontal stresses distribution, as well as stresses intensity distribution. The recommended engineering decisions have been substantiated and the SSS of fastening and security structures has been analysed. A certain reserve of the fastening structure load-bearing capacity as part of the frame support and the combined roof-bolting system has been revealed. An evidence base has been created for the measures development on conducting and maintaining mine workings in the zone of the stope works influence. The recommendations have been developed on the protecting pillar formation with a width of at least 40 – 45 m to exclude the stope works influence.

1 Introduction

At present, there are trends to drive out the hydrocarbons from use in the energy sector. But, according to long-term predictions, the volumes of coal output will grow to 2040 by 20% from 7.7 to 9.23 bill t. The data presented in the work [1], show the presence of a positive attitude to the coal industry development in Ukraine. Coal is the only energy raw material, the reserves of which are potentially enough to ensure the energy security of our state and promote the development of the metallurgical and chemical industries. If in the structure of world reserves of the organic fuel main types, coal is 67%, then in Ukraine – 95.45% [2].

The necessity to introduce innovative coal technologies into production has a political, social-and-ecological, as well as economic basis.

One of the resource-saving trends in extraction of mineral resources is the optimization of the protecting pillars parameters, in which up to 70% of standard quality coal reserves are concentrated in exploited fields. This problem is complex to solve at the Western Donbas mines that is explained by specific mining and geological conditions [3, 4]. Coal in this region is hard enough (hardness coefficient according to M. M. Protodiakonov $f = 2.0 – 3.5$), and the enclosing rocks – argillites, siltstones and sandstones are weakly stable ($f = 0.8 – 2.5$). Therefore, when conducting the work, decisions were made to leave the pillars with large width [5].

The operational state of mine workings depends on measures aimed to protect them from the rock pressure manifestations, which are provided for at all stages of the mine working existence: design, construction, operation, and abandonment [6, 7]. Unfortunately, the planned and implemented measures sometimes do not make possible to maintain a stable state of mine working [8, 9]. On the other hand, the experience of coal mining enterprises exploitation indicates the situations arising where, according to well-founded design decisions, the stability of mine workings is excessive and is ensured by the unnecessary waste of resources, primarily mineral resources, for example, within natural protecting objects, the so-called pillars. Such pillars enable to protect mine workings, and the mineral resources loss within the entire mine reaches 10% or more of the mine's total reserves. That is why, determining the geometric pillars dimensions is an important and urgent task, the solution to which will reduce losses, increase output and optimize the coal product costs [10, 11].

The group of pillars is of particular interest, designed to ensure the stability of inclined overburden workings. This group includes, first of all, slopes and gravity inclines, of which should be 3, when uncovering the panel: slope (gravity incline) and two passage ways, between which there are pillars preventing the mutual influence of these mine workings. In addition, there are also pillars, the purpose of which is to protect the complex of mine workings from the bearing pressure influence at the front of the stope works. The width of such pillars with increasing depth of mining reaches 150 – 200 m [12], which, of course, leads to significant

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losses of coal reserves prepared actually for mining.

Thus, the development of a methodology for a possible reduction in the protecting pillars width is an urgent applied research task, which is important for the mining industry. The second solution component to this problem is the substantiation of resource-saving technologies for fastening and maintaining mine workings in the zone of the stope works influence.

2 Research methodology, analysis of mining-geological and mining-engineering conditions

The problem of optimizing the protecting pillar width was solved using the example of "Dniprovska" Mine of Dniprovska Mine Group, DTEK "Pavlohradvuhillia", PRAT. The plans for mining operations development along the seam C_{10}^{l} in "Dniprovska" Mine provide for the further development of the North Drain Slope (NDS) to the width of two extraction sites: the 1100 longwall face will be mined-out in 2020, the extraction of reserves at the 1001 longwall face will be completed in 2021. To ensure the two indicated mining sites operation, in 2019 it is planned to develop the NDS to the area of entry to the 1100 prefabricated drift, and in 2020 – until junction with the 1101 prefabricated drift.

The NDS protection from the stope works influence in the 1100 and 1001 longwall faces is provided by trapezium-shaped coal pillars, in which the minimum distance L_{pr} from the face entry to the NDS is 85 – 90 m. According to the normative documents on the mine workings location, such a width of the protecting pillar should be sufficient to maintain the NDS of the seam C_{10}^{l} in a satisfactory state for the entire period of its exploitation. On the other hand, the experience of mining operations in the Western Donbas indicates the ambiguity of the link between the protecting pillar width and stability degree of the main preparatory mine workings [13]: their state is enough satisfactory (in accord with safety standards and rules) with a protecting pillar width of several tens of meters. On the contrary, the case when they are protected by a coal pillar with a width of about 200 m and sometimes even more does not meet the requirements for safe operation. Obviously, a differentiated approach is required when choosing the protecting pillar width, based on the analysis of geomechanical factors influencing the massif state in the location area of a newly constructed NDS site of the seam C_{10}^{l}. Thus, the task of research is to study the possibility of reducing the protecting pillar width along with the measures development on conducting and maintaining the NDS of the seam C_{10}^{l}, taking into account the influence of the rock pressure anomalies during mining of the 1100 and 1001 longwall faces.

In accordance with the plan of mining operations development (Figure 1), at this mine field site, the depth of placement of the constructed NDS site of the seam C_{10}^{l} is $H = 420 – 450$ m, and tectonic disturbances can occur along the trace of mine working. According to Geological Survey data of "Dniprovska" Mine, complex mining-geological and hydrogeological conditions are expected when developing the NDS of the seam C_{10}^{l}, which are conditioned by several factors. Firstly, mine working crosses two dangerous areas.

Secondly, the immediate bottom rocks of the coal seam C_{10}^{l} represented by siltstone, are characterized by low strength characteristics, and when being moistened, they are prone to soaking and heaving [14].

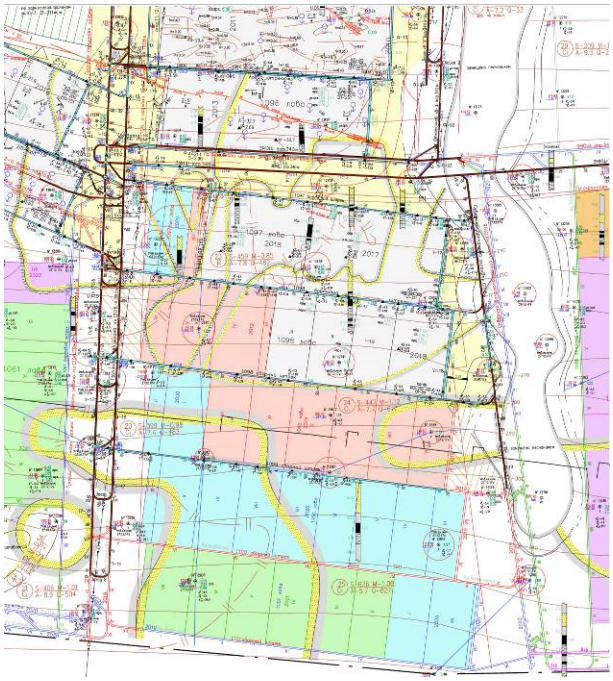

Fig. 1. Excerption from the plan of mining operations along the seam C_{10}^{l} of "Dniprovska" Mine along the NDS trace in the area of the planned 1100 and 1001 longwall faces.

Thirdly, the water-cut of mine working is conditioned by the sandstone occurring in the main roof and coal seams C_{10}^{l} and C_{10}^{u}, as well as the possible water ingress in the crossover point of the tectonic disturbances of "fault" pattern [15]. The expected water inflow in the face space is 1.5 – 6.0 m^3/h, and with long stops, an increase is possible of up to 10 m^3/h. Furthermore, an additional water inflow will be formed from the 1097 prefabricated drift, 1097 boundary drift, 1098 prefabricated and 1099 prefabricated drifts, which in total will increase water inflow through the NDS of the seam C_{10}^{l} up to 25 m^3/h.

The North Drain Slope of the seam C_{10}^{l} will be developed along the coal seams C_{10}^{l} and C_{10}^{u}, as well as along the rocks of their roof and bottom, represented by argillite, siltstone and sandstone, which occur at an angle of 3 – 6° in the north-east direction.

The stability of the enclosing massif and the preliminary prediction of rock pressure manifestations were assessed based on the geological sheet along the NDS of the seam C_{10}^{l} 265 m horizon (Figure 2).

The coal-bearing stratum geology at the newly constructed NDS site of the seam C_{10}^{l} has been studied in two directions:

– the area of the bearing pressure propagation in the protecting pillar during mining out the 1100 and 1001 longwall faces;

– assumed rock pressure manifestations around and

on the SDS contour to substantiate its fastening scheme.

At the first site of the mine working length, the following peculiarities of the coal-bearing stratum state are predicted.

The immediate roof of the seam C_{10}^{l}, represented by argillite with a thickness of 1.2 m, is characterized by an increased tendency to cleavage and collapse, despite the mean lithotype hardness (uniaxial compression resistance in the sample σ_{compr} = 20.6 – 21.5 MPa). The unstable state of immediate roof (when it is outcropped) is determined by two reasons. The first reason is a very low argillite adhesion to the coal seam C_{10}^{l} and the overlying sandstone. The second reason is that both of these lithotypes are water-flooded and the small argillite thickness causes its intense water saturation throughout the entire volume with a loss of hardness at least twice according to [16].

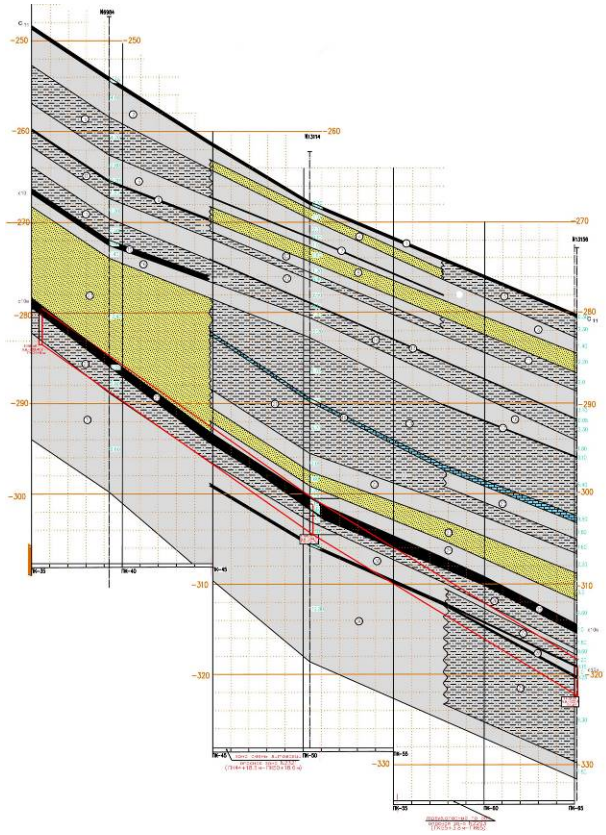

Fig. 2. Predictive geological sheet along the NDS of the seam C_{10}^{l} 265 m horizon.

Weak resistance of the immediate roof plays an ambiguous role in the issues under study. From the point of view of the bearing pressure formation in the protecting pillar, the weak, easily deformable and weakened immediate roof functions as a damper, partially smoothing out the stresses concentrations in the area of the border with the mined-out space. On the other hand, it is possible to unambiguously predict argillite collapse throughout entire its thickness over the NDS arch, which forms a relatively small vertical and oblique load on the mine working support.

The adjacent two layers of the main roof are represented by sandstone with a thickness of 1.6 m and argillite with a thickness of 2.0 m. The sandstone is water-flooded and loses its hardness from 20 to 40% [16] with its rather mean compressive resistance in the sample σ_{compr} =11.7 – 53.3 MPa. Argillite is not hard (σ_{compr} = 7.7 – 26.4 MPa), and with partial moistening of its lower part from the water-bearing sandstone, it can be considered a weak unstable lithotype. Moreover, the adhesive forces on the bedding surfaces are very low, and with horizontal shifts (for example, in the bearing pressure zone), the contacts are completely disturbed. Above siltstone occurs, divided by an interlayer of limestone (with a thickness of 0.4 m) into two parts: lower – with a thickness of 5.7 m with σ_{compr} = 23.5 – 29.7 MPa; upper – with a thickness of 6.7 m with σ_{compr} = 12.0 – 34.1 MPa. With a relatively mean hardness and a predominantly naturally moist state of siltstone, its behaviour can be assessed as a quite stable due to the increased thickness.

The roof rocks composition is described to a height of 17.6 m; the overlying lithotypes, according to the existing concepts [10, 11], will be deformed (during the stope works operations) without discontinuity, although it is likely that thick siltstone layers will be resistant even when partially divided into blocks due to formation of thick thrust-block systems. In the lower part of the main roof, weakened sandstone and argillite with a medium thickness will definitely collapse into the mined-out space, and the rock cantilevers, hanging from them, have a small length. Both above factors facilitate the formation (at the mined-out space boundary) of the bearing pressure zone with a low stresses concentration, which will decrease when moving backward into a virgin massif in the direction of the NDS of the seam C_{10}^{l}. Around the mine working itself, the weakened rocks border area formation is possible, since sandstone and argillite in the roof are not sufficiently stable.

The following lithotypes are located in the sides and the bottom of the NDS of the seam C_{10}^{l}: the coal seam itself is quite hard (σ_{compr} = 40.0 – 50.0 MPa), but fractured and water-flooded with weakened contacts along the bedding planes; in the immediate bottom, siltstone with a thickness of 1.3 – 1.8 m, most likely water-flooded with σ_{compr} = 15.6 – 24.1 MPa; in the main bottom, argillite occurs, divided by the coal seam C_{10}^{u} into two layers with σ_{compr} = 10.0 – 33.2 MPa. The indicated massif structure in the sides and the nearest layers of the mine working bottom suggests the development of an increased lateral bearing pressure onto the support, and the bottom water-cut provokes its intense heaving [17, 18]. The so-called “stamp effect” should be added to this [19], when a harder coal seam presses-out (due to an increased vertical pressure) the less hard and easily deformable underlying rocks into the sides and the bottom of mine working.

Therefore, the following preliminary conclusions can be made at the first site of the dangerous zone:

– in a coal protecting pillar, in the area of the border with the mined-out space, the bearing pressure zone will be characterized by reduced stresses concentrations;

– a differently vectored rock pressure will be formed around the NDS of the seam C_{10}^{l} with different intensity of the border rocks displacements in the roof, sides and bottom of mine working;

– development of an unstable state of argillite and sandstone to a height of up to 4.8 m is possible in the roof of the NDS of the seam C_{10}^{l}, but it can be dramatically restricted by applying the combined roof-bolting systems [20 – 22], with which the vertical and oblique load in the arch will decrease to safe values;

– an increased lateral load on the prop stays of the frame support is predicted in the sides of mine working, and to maintain their stable shape, it is proposed to set the lateral roof-bolts with their tail joints connected with the prop stays of the frame by means of pliable (rope) binders [23];

– an intensive heaving is supposed in the bottom of the NDS of the seam C_{10}^{l}, which is partially restricted by lateral resin-grouted roof bolts, and the main method to resist to heaving is the same – periodic bottom rocks ripping.

At the second site of the NDS length of the seam C_{10}^{l}, similar rock pressure manifestations are predicted, but there are some peculiarities.

The first peculiarity is connected with a change in the lithology of the seam C_{10}^{l} roof rocks and the deviation of mine working into its bottom. Now, a layer of siltstone with a thickness of 1.5 – 1.8 m is located above the mine working arch, and beginning with PK61, an interlayer of argillite with a thickness of 0 – 0.6 m appears directly on the contour as a kind of friable roof by analogy with the stope faces. The average compressive resistance of siltstone in the sample is 19.9 MPa, argillite – 21.6 MPa. Both lithotypes are of medium-bedded stratification and their water saturation from the seam C_{10}^{l} is predicted. For this reason, an unstable state of border rocks should be expected in the NDS roof to the thickness height of siltstone and argillite. The coal seam C_{10}^{l}, despite its relative hardness, is water-flooded and fractured; therefore, it can be classified as weakly stable. The argillite of the immediate roof of the seam C_{10}^{l} with a thickness of 2.0 – 2.6 m is water-flooded, hence, it is difficult to express an unequivocal opinion in terms of its stability. The first layer of the main roof is represented by sandstone with a thickness of 2.4 – 3.0 m with an average compressive resistance of 32.5 MPa, and despite its water-cut, the lithotype can be assessed as stable.

Thus, formation of a vast region of unstable rocks up to 6.0 m high over the NDS arch of the seam C_{10}^{l} is possible, which is able to form a vertical and oblique load of a dangerous value.

From the point of view of the protecting pillar state at the border with the mined-out space, an attention should be paid here to the change in the composition of the main roof rocks of the seam C_{10}^{l}. There partial replacement occurs of siltstone with argillite and two lithotypes with medium thickness are formed (1.6 m and 1.8 m, respectively). Hard limestone is located above (σ_{compr} = 94.3 – 133.0 MPa), but its low thickness (up to 0.8 m) and fracturing indicate weak stability. The total thickness of the described lithotypes is up to 12.0 m and a variant of roof stratifications development to such a height is quite possible. The variant of the hinged-block displacement zone extension through the thickness (6.4 m) of the overlying siltstone up to a coal interlayer with a thickness of 0.1 m is less possible. Nevertheless, in both cases, the structure of the roof rocks of the seam C_{10}^{l} can be characterized as predominantly medium-bedded, with the rock cantilevers insignificantly overhanging into the mined-out space. Therefore, moderate stresses concentrations in the bearing pressure zone of the coal pillar should be predicted.

The second difference of the studied dangerous zone is a change in the rocks structure of the seam C_{10}^{l} bottom. Here, throughout the mine working height, mainly thin layers of argillite and siltstone are located, as well as coal seam C_{10}^{u} with a two-band structure. With a relatively insignificant hardness, all lithotypes are water-flooded, which, with a significant geostatic pressure (H = 420 – 450 m), predicts the formation of large areas of weakened rocks in the NDS sides, as well as the development of a significant lateral load onto support.

The NDS bottom of the seam C_{10}^{l} is represented by a thick (9.3 m) siltstone with an average compressive resistance in the sample of 19.9 MPa. The siltstone stratification and a probability of water saturation of its upper bands suggest the development of heaving process from moderate to intense. However, in the mine working sides, there is no sufficiently rigid lithotype, and the existing thin and weakened lithological varieties are not able to create a “stamp effect”. Therefore, it is expected that the predicted heaving will be of moderate value.

Summing up the analysis results of mining and geological situation as a whole around the NDS sites of the seam C_{10}^{l}, constructed according to the plan of mining operations, a preliminary assessment should be made:

– moderate stresses concentration in the bearing pressure zone along the protecting pillar width in the border area with the mined-out space is unlikely to influence the mine working state, and the possibility of reducing the protecting pillar width will be substantiated below when performing a computational experiment;

– it is predicted the development of differently vectored rock pressure manifestations on the mine working contour and it is recommended to use various engineering decisions to ensure its stability, in particular, combined roof-bolting systems and the structural coupling of lateral resin-grouted roof bolts with the prop stays of the frame support.

3 Substantiation of the possibility to reduce the protecting pillar width

A preliminary expert assessment of the coal-bearing massif state in the boundary area of the protecting pillar of the SDS of the seam C_{10}^{l} and the mined-out space, when the 1100 and 1001 longwall faces move backward from the face entry, indicates the low stresses concentration in the bearing pressure zone. The reason for this statement was revealed in the works [21, 22, 25]: easily deformable and relatively weak layers of the roof are not able to form any stretched rock cantilevers on the border of the mined-out space, which concentrate the bearing pressure near the protecting pillar border; low deformation characteristics of lithotypes (caused by discontinuity, stratification and water-cut), due to

damping properties, localize the high rock pressure (HRP) areas at a limited coal pillar length; hence, the stope works influence in the 1100 and 1001 longwall faces does not extend in a protecting pillar to remote areas, including the area where the NDS of the seam C_{10}^{l} is located.

The above representations have been tested by means of a computational experiment using proven techniques [18, 23, 26-28] as applied to the analysed mining and geological conditions. Taking into account the need to consider the complex of geomechanical and mining factors a conclusion about feasibility of modern computer programs by the FEM use is obvious for the solution of set problems: models creation – *Solid Works* program, the SSS calculation of the system elements in elastic approach – *Desain Star* application; materials anisotropy consideration – *Cosmos-M* program, wide opportunities of *Ansys* complex. The computational experiment results are presented in the form of curves of vertical σ_y, horizontal σ_z and intensity σ stresses distribution along the protecting pillar width z, including the mined-out space to a length approximately twice the step of primary setting of the main roof.

Analysis of the vertical stresses σ_y curve (Figure 3) has revealed the following results.

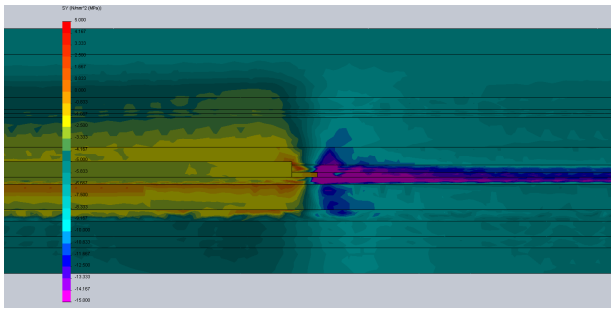

Fig. 3. The vertical stresses σ_y distribution across the protecting pillar width.

The dimensionless indicator K_y is the most informative parameter, which determines the effective value σ_y relative to geostatic vertical pressure γH of virgin massif (as denoted here: H – depth of mining operations; γ – weight-average unit specific gravity of rocks in the coal-overlaying formation). The second indicator is the distance $l_{y,z}$ of a specific concentration value K_y distribution into the roof and bottom of the seam C_{10}^{l} (distance l_y) and across the protecting pillar width (distance l_z).

In full compliance with existing concepts, the highest concentrations of K_y were recorded near the protecting pillar border, adjacent to the mined-out space of the 1100 and 1001 longwall faces; the maximum distances $l_{y,z}$ of each discrete value propagation K_y are also noted here. Thus, the concentrations of $K_y \geq 2.0 - 2.5$, capable of weakening the lithotypes of the coal-bearing stratum, develop into the seam C_{10}^{l} roof to a height of up to 1.8 m; into the bottom – to a depth of 1.6 m; across the pillar width l_z – 3.5 – 4.0 m and capture the immediate roof rocks, and in the coal seam itself, the local areas are observed at a distance of up to 3.0 – 3.5 m; the greatest distance l_z to 5.0 is recorded in the immediate bottom rocks. The next category of vertical stresses concentration $K_y = 1.5 - 1.8$ is able to partially weaken the rocks of the immediate roof and bottom, taking into account their probable water saturation, but the harder lithotypes (coal seam C_{10}^{l} and sandstone of the main roof) retain their continuity and are capable of further resistive action to vertical rock pressure. The width of the partial weakening area is up to 8 – 9 m in the immediate roof, and up to 10 – 12 m in the immediate bottom.

The concentration level $K_y \leq 1.5$ has the largest propagation area, in which the lithotypes of the adjacent coal-bearing stratum mainly retain their natural structure, and some local discontinuity is conditioned by water saturation, stratification and fracturing of the weakest rock layers – siltstone and argillite of the immediate bottom. As for the argillite of the immediate and main roof (occurring in the dangerous zone), the following situation is predicted here in the area of the protecting pillar with a width $l_z \leq 8.0$ m.

It was previously noted that the immediate roof is definitely weakened, and the water-flooded sandstone remains continuity at $l_z \geq 3.5 - 4.0$ m. But the second layer of the main roof, occurring above sandstone, is exposed to partial water saturation, and its separate samples (when tested for compression) have shown very low values of $\sigma_{compr} = 7.7$ MPa. Such compressive resistance, even with $K_y < 1.5$, presumes argillite weakening of the main roof second layer to a coal pillar width of up to 8.0 m. Argillite with the same strength properties is the fourth layer of the main roof, located at a height of about 10 m from coal seam C_{10}^{l}. At this height,
a concentration of $K_y = 1.5$ is localized and is not propagated further. However, it is necessary to take into account a sufficiently large (for the Western Donbas conditions) depth of $H = 420 - 450$ m of mining operations and here the geostatic pressure, even at low concentrations $K_y = 1.2 - 1.3$, can partially weaken the separate argillite bands with $\sigma_{compr} = 7.7$ MPa. Therefore, it is quite predictable a formation of the weakly stable rocks area (in the dangerous zone) to a height of 12 – 13 m, where a thin limestone layer occurs.

This conclusion refers only to a border area of the protecting pillar with a width of up to 4.0 m, but in weak argillite layers of the main roof it can be propagated over a width $l_z = 10 - 13$ m. Further into massif, the vertical stresses concentrations dramatically decrease, which reflects the following parameters:

– at a distance $l_z = 30 - 32$ m, insignificant concentrations of $K_y = 1.2 - 1.3$ level completely disappear in the main roof and its state is determined by the geostatic pressure of virgin massif; that is, at such a distance, the stope works influence is absent;

– in the immediate roof and the first layer of the main roof, the increased concentrations of $K_y = 1.5 - 1.8$ level are propagated locally to a distance of $l_z = 22 - 27$ m mainly due to the sandstone tensile strain;

– in the coal seam C_{10}^{l}, due to its increased rigidity, the concentrations of $K_y = 1.8 - 2.0$ are acting up to the level of $l_z = 18 - 22$ m; for the same reason, the stope works influence in the immediate bottom can be

observed up to l_z = 22 – 24 m.

With further removal from the boundary of mined-out space, its influence on the of vertical stresses σ_y distribution disappears – the protecting pillar itself and the coal-bearing stratum approach to the state of a virgin massif.

Thus, according to the factor of the component σ_y action, the absence of the stope works influence in the 1100 and 1001 longwall faces at a distance of more than 32 m from the face entries has been proved. Therefore, with a certain safety factor of the prediction, it is quite expedient to leave the coal pillar with a width of 40– 45 m for the protection of the NDS of the seam C_{10}^{l}.

This conclusion has been tested by means of analysing the curve of the horizontal stresses σ_z distribution across the protecting pillar width z and the stresses intensity σ, confirming the conclusions on vertical stresses.

Given a similar influence according to the action factors of vertical stresses σ_y, horizontal stresses σ_z and stresses intensity σ, it can be considered reasonable to make an engineering decision on the NDS protection of the seam C_{10}^{l} by a coal pillar with a width of 40 – 45 m.

4 Measures development on conducting and maintaining the NDS of the seam C_{10}^{l} in the zone of the 1100 and 1001 longwall faces influence

The measures to conduct and maintain the NDS of the seam C_{10}^{l} have been developed on the basis of scientific research and practical experience of the mine workings exploitation in the mining and geological Western Donbas conditions [3, 4, 19]. Earlier, the possible rock pressure manifestations has been preliminary assessed and general recommendations for ensuring the stable state of the NDS of the seam C_{10}^{l} has been made.

In this chapter, the recommended engineering decisions have been substantiated, including application of the method of computational experiment.

In the previous studies, a system of evidence was given that there is no stope works influence in the 1100 and 1001 longwall faces with a protecting pillar width of 40 – 45 m. Here, substantiation is continued of absence of the stope works influence, based on the implementation of the following algorithm of actions.

Firstly, the main negative factors were distinguished earlier that (according to preliminary expert assessment) can significantly influence on the SDS stability of the seam C_{10}^{l} in the area of the 1100 and 1001 longwall faces location:

– possible asymmetry of the load on the mine working fastening structure needs to be tested by determining the SSS of the maintenance scheme main elements;

– there is a probability of arising an extensive arch of ultimate equilibrium around the NDS, which is able to form a high vertical and oblique load from the side of the roof rocks; the SSS analysis is required here of the previously recommended fastening structure in terms of effectiveness of its resistive action to rock pressure;

– an increased lateral load development on the fastening structure is possible – to check this, it is necessary to study the SSS of the prop stays of the frame support: assess the probability of their plastic bending.

Secondly, the measures substantiation to maintain the NDS of the seam C_{10}^{l} is performed on the fastening structure model, which is called “experimental” for the following reasons:

– to resist to vertical and oblique rock pressure, the frame support of TSYS series is strengthened by a combined roof-bolting system according to the recommendations [29, 30] of the resin-grouted roof bolts and rope bolts arrangement;

– a central prop stay of the strengthening support is set in the frame arch to control the danger level of the vertical and oblique loads development; it performs the functions of a “detector”, which assesses the degree of its loading, the sufficiency of the used fastening elements or the necessity to supplement them with other structures; in addition, according to arising bending deformations in the central prop stay of the strengthening support, the level of the vertical load asymmetry is determined, that is, indirectly, the degree of the stope works influence;

– more significantly, the influence degree of the stope works in the 1100 and 1001 longwall faces is assessed by the level of loading the second “detector” – of the lateral prop stay of the strengthening support, erected from the side of the coal pillar;

– the third “detector” is the prop stays of the TSYS frame support – according to the parameters of the stresses components distribution in them, the danger degree of plastic bending is determined, which serves as an indirect indicator of the lateral load value; then, the question should be solved, whether it is necessary to set (or not to set) the lateral resin-grouted roof bolts and strengthen the frame prop stays with the help of pliable binders with the roof-bolt tail joints.

The described methodological technique in the technology of performing the computational experiment enables, in our opinion, to solve all the tasks set for substantiating the measures to maintain the NDS of the seam C_{10}^{l} in the zone of the 1100 and 1001 longwall faces influence.

The SSS study of each main fastening structure element is performed on the three most informative components: vertical stresses σ_y, horizontal stresses σ_z and stresses intensity σ.

A sequential analysis of the peculiarities of each component distribution has revealed that the vertical stresses σ_y curve, presented in Figure 4.

The first significant peculiarity of the curve σ_y is observed in the cap board of the frame support and characterized by its quite significant underloading (compared with the estimated yield limit σ_{yield} of the SCP steel), despite the action of stresses with different signs.

The revealed situation with a very low loading of the frame cap board can be explained by three reasons:

– low vertical and oblique load from the limited dimensions of the arch of ultimate equilibrium;

– high reaction of the central and lateral prop stays of the strengthening support, which unloads the frame cap

board;

– efficient performance of the combined roof-bolting system to create an armoured and rock plate with high load-bearing capacity.

The second peculiarity of the curve σ_y is the combination of a significant loading of the frame prop stays with a relatively uniform distribution of σ_y in the SCP cross section.

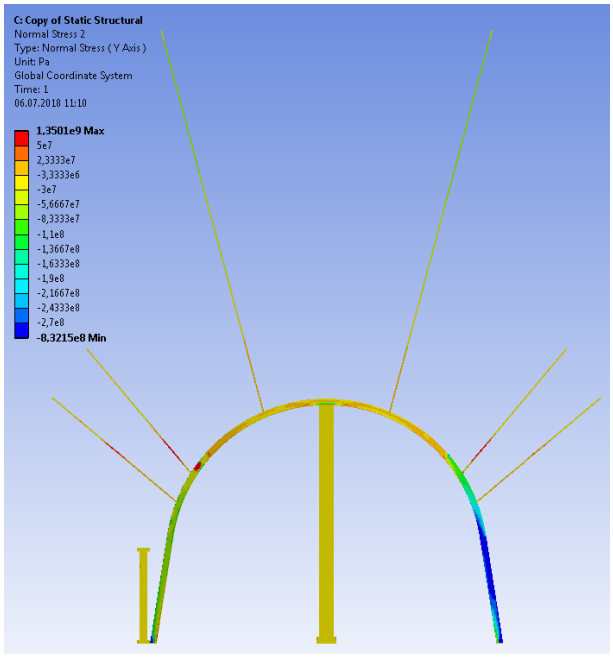

Fig. 4. Curve of vertical stresses σ_y in the preliminary variant of fastening structure of the NDS of the seam C_{10}^{l}.

The above results make possible to draw the following conclusions. On the one hand, the frame prop stay experiences a significant vertical load, but within the permissible load-bearing capacity. This indicates the assumptions validity about the formation of an extensive arch of ultimate equilibrium. On the other hand, the frame prop stay copes with resistive action to lateral load, since there is practically no bending moment throughout its main height (about 80 – 85%); only in the bearing area of the prop stay, a bending moment acts with a value that is not dangerous from the point of view of its plastic bending. The latter circumstance indicates the inexpediency of hardening the NDS sides with the roof-bolts and strengthening the frame prop stays with pliable binders.

Similar result σ_y, in terms of quality, has also been obtained for the left frame prop stay, adjacent to the protecting pillar. Only here, the value of compressive stresses σ_y was 30 – 33% less than in the right frame prop stay, which is conditioned by the influence of the lateral wooden prop stay of the strengthening support.

From the third peculiarity of σ_y distribution, described above, the following conclusions can be drawn. Firstly, there are no bearing pressure effects in the protecting pillar (with a width of 40 m) on the increase in vertical load in the adjacent prop stay of the frame. On the contrary, the total resistance reaction of the lateral wooden prop stay and frame prop stay is slightly reduced. Secondly, the lateral wooden prop stay is not only weakly loaded, but also does not experience any bending forces. This indicates the absence of increased rock pressure from the side of protecting pillar.

The fourth peculiarity of the curve σ_y relates to the central wooden prop stay of the strengthening support and reflects two facts: very low level of loading about 15 – 20% of the estimated load-bearing capacity value; practical absence of bending moment throughout the entire height. The first fact indicates that the frame support and the combined roof-bolting system quite cope with rock pressure: the central prop stay of the strengthening support is not necessary. The second fact notes the absence of any significant asymmetry in the fastening structure loading, and, consequently, the stope works influence through the protecting pillar.

Summing up the analysis results of the vertical stresses σ_y distribution in the fastening structure of the SDS of the seam C_{10}^{l}, it is necessary to highlight the following basic provisions:

– the fastening structure as part of the frame support of the TSYS series and the combined roof-bolting system resists to rock pressure with some reserve of load-bearing capacity;

– with the protecting pillar width of 40 m, the stope works influence in the 1100 and 1001 longwall faces is not revealed;

– the conclusions of the preliminary expert assessment were amended in terms of lack of the necessity to set resin-grouted roof bolts in the mine working sides and their connecting with the prop stays of the frame support.

The horizontal stresses distribution and the stresses intensity in the elements of the fastening structure supplement the earlier conclusions about its stability degree.

The almost complete absence of bending moment both in the prop stays of the frame (with the exception of an area of their bearings) and in the wooden prop stays of the strengthening support indicates the same absence of oblique load from the side of the coal pillar. It can be concluded from here that the width 40 m of the last excludes the stope works influence in the 1100 and 1001 longwall faces.

Assessing the degree of loading the roof bolts of the combined roof-bolting system, it should be noted that there is a reserve of load-bearing capacity of at least 30 – 35%, which is included into the safety factor of the recommended fastening structure.

Summing up the performed research results, it can be considered that the evidence base has been created for the measures development on conducting and maintaining the NDS of the seam C_{10}^{l} in the zone of the 1100 and 1001 longwall faces influence in “Dniprovska” Mine.

5 Measures on conducting and maintaining the NDS of the seam C_{10}^{l}

To ensure a stable state of the North Drain Slope of the seam C_{10}^{l} for the entire period of its exploitation, the

following measures have been developed:

1. In order to exclude the stope works influence in the 1100 and 1001 longwall faces, planned by the time schedule, to form from their side a protecting pillar with a width of at least 40 – 45 m.

2. During the period of the new site development of the NDS of the seam C_{10}^{l}, apply the fastening structure, including the frame support of the TSYS series and the combined roof-bolting system in accordance with the scheme in Figure 5.

3. The frame support is set with a step of 0.8 m with a tightening of the interframe space by means of a cyclone fencing.

4. The combined roof-bolting system includes 6.0 m long rope bolts, being set in a chessboard pattern (with respect to the mine working sides) with a step of 3.2 m, as well as two pairs at a time resin-grouted roof bolts of 2.4 m long erected in the middle of the interframe space in each side with a step of 0.8 m.

5. To be actively engaged in the work to resist to the border massif stratification, the combined roof-bolting system is erected with the minimum possible (for technological reasons) lagging behind the drifting face.

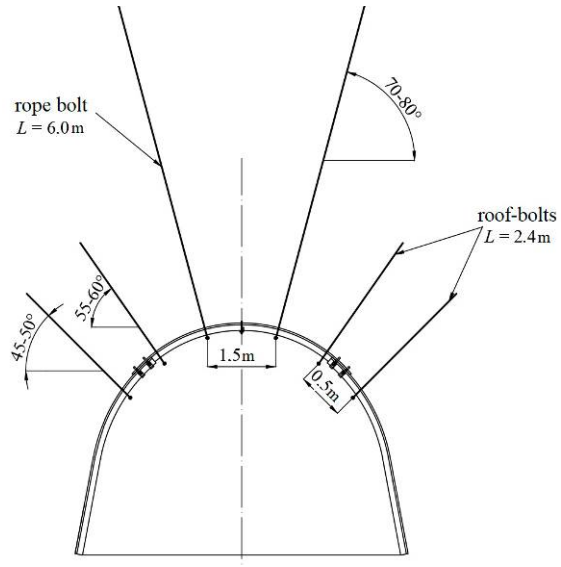

Fig. 5. Scheme for the fastening structure of the NDS of the seam C_{10}^{l}.

The experimental and industrial testing of frame-roof bolt support with self-regulated load redistribution, has shown its high efficiency in terms of mine working sides displacements restriction. The mine working is in stable condition along the whole its extent, and displacements of rock contour are considerably lower than vertical and side constructive support yield.

6 Conclusions

Summing up the performed research results, it can be concluded about the methodology development for optimizing the protecting pillars parameters. Using the example of "Dniprovska" Mine of DTEK "Pavlohradvuhillia" PRAT and, with the application of the method of computational experiment, the possibility of reducing the protecting pillar width has been proven. Based on the SSS analysis of the "massif – fastening system – protecting elements" system state, the measures have been developed on conducting and maintaining of mine workings in the zone of the stope works influence.

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Online ore monitoring using EDXRF method on process conveyor belts at Kazakhmys Corporation LLC operations

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Abstract. The paper discusses organizing online ore monitoring on process conveyor belts at the operations of Kazakhmys Corporation LLC using EDXRF method implemented as an ore-controlling station (OCS) targeting ore size of -300 mm. OCS is supposed to achieve the objective of providing reliable silver detection measurements in the range of 1+ ppm. Objects of monitoring: copper-containing polymetallic ores delivered to Zhezkazgan, Balkhash and Karagaily processing plants for treatment (target elements include copper, zinc, lead, silver, cadmium, and iron) as well as ores transported by the main underground feeder belt at Nurkazgan Mine (copper, zinc, lead, silver, molybdenum, and iron). The ultimate of the studies was to produce an online report on quality and quantities of ore and metals delivered from each of ore suppliers; to adjust the tonnages dispatched by the various shafts and open pits in the online mode; obtain reliable proof for unbiased redistribution of metals back to the mining operations. Equipment used during the studies: EDXRF OCS RLP-21T. Key features of the unit are also discussed. The results of bench-scale testing as well as industrial application of OCS RLP-21T are discussed leading to the conclusion of successful online monitoring of silver in ores sized from +1 ppm to -300 mm. The photographs were provided by S. A. Yefimenko.

1 Introduction

Pertinent issues in minerals mining include integrated mineral resource mining, underground resource reproduction, and maximum recovery of useful components during ore processing. Integrity of mineral use will radically reduce intensive technogenic environmental impact of mining operations and improve the geological and environmental conditions in Ukraine's industrial regions. Substantiation of efficient recovery of rare, valuable and noble metals in such minerals is an urgent problem for iron ore processing in Kryvyi Rih iron ore basin.

For example, ferruginous quartzites of Kryvyi Rih iron ore basin contain 0.114-0.3 g/t of gold. Gold occurs in the finely dispersed state in the form of elongated grains of $(3\text{-}15)\times10^{-3}$ mm and plate aggregates with rounded edges in magnetite and in quartz.

Gold is found in low-grade magnetite ores of Kryvyi Rih iron ore basin and is unevenly distributed in different deposits. In the initial ore of Northern GOK, bound-state gold grades range from 0.016 g/t to 0.03g/t, which was confirmed through mercury amalgamation studies detecting no free gold. In the south of Kryvyi Rih iron ore basin, the ore mined from Novo-Krivorozhsky and Ingulets GOKs has a somewhat higher average gold grade of 0.034-0.067 g/t, reaching 0.11-0.347 g/t in some areas.

Mineralogical studies have confirmed that free gold is contained only in ore sized less than $(8\text{-}10)\times10^{-3}$ mm, therefore less than 10% is disclosed. The remaining 90% of the total gold contained in the initial ore is dispersed in quartz and silicates, as well as in magnetite, carbonates and other minerals. Higher gold grades as compared with average background minerals is found in iron ore areas with a higher content of iron sulfides, pyrite and pyrrotite. The discovered free gold in the form of thin plates is foil gold.

Determination of the grades not only for gold but also for all valuable elements contained in iron ores will enable assessing their extraction prospects in the form of by-products as early as at the stage of iron ore mining.

While conducting investigations into this matter, it is reasonable to study experience of Kazakhmys Corporation LLC.

Kazakhmys Corporation LLC is the largest copper producer in Kazakhstan that develops copper sandstones deposits of Zhezkazgan and Zhaman-Aybat (Cu, Pb, Zn, Ag, Re, Cd, S, Os), a gold-copper-porphyry deposit in Nurkazgan (Cu, Au, Ag, Mo, Se, S), pyrite-copper-lead-zinc deposits of Kusmuryn and Akbastau (Cu, Zn, Pb, Au, Ag, Cd, Se, S, Te), Shatyrkol porphyry-copper deposit (Cu, Mo, Au, Ag, Te, Se, U), Abyz gold-pyrite-copper-lead-zinc ore (Pb, Zn, Cu, Au, Ag, S, Se, Te, Cd , In, Hg), and Sayak group of copper-skarn deposits (Cu, Mo, Fe, Au, Ag, Bi, Te, Se, Re).

Deposits are developed using underground and open-cast mining methods at Zhezkazgan, Balkhash and Karaganda production sites. Copper grades in mined ores

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have been decreasing steadily. Economic losses from the downward trend were offset by associated silver production.

Silver grades are low and therefore economic sustainability of mine production planning systems will heavily depend on possible online monitoring of copper and silver grades in exploration phase, in preparation and production mining as well as during ore delivery to processing plants. Based on the above, implementation of online monitoring of copper and silver grades would be addressing two independent objectives as follows:
- online monitoring of ores at the stage of exploration, mining and production;
- online monitoring of ores in transit to processing facilities. This study helps achieve this specific objective also addressing the issues associated with easing tensions arising between mining and ore processing facilities with regard to cyclone overflow metal redistribution.

This objective was being addressed within the framework of the Import Substitution Program administered by the Republic of Kazakhstan in the mining sector and as part of the range of projects aiming to retrofit and expand production at Kazakhmys Corporation LLC in 2017–2025.

Online monitoring of ores delivered to processing plants is highly challenging in technical terms due to the following factors:
- large ore size of -300 mm;
- often heavily slimed ore;
- low silver grades (from 1 to 25 ppm);
- complex ores;
- ores come from different mining sources;
- at one of the facilities (Balkhash Processing Plant) ores are treated in a blend with Balkhash Copper Smelter slags characterized by highly complex grades matrix.

The above-listed factors clearly indicate that such a difficult objective has never been addressed successfully before regardless of the methods applied.

This study focused on ores brought to processing plants on conveyor belts as well as the material carried by underground conveyor belt at Nurkazgan Mine.

2 Method and geophysical apparatus

This study pursues the goal of establishing a unified, reliable and highly efficient online monitoring system of tracking the ever changing chemical composition of copper-bearing polymetallic ores at mining and processing operations of Kazakhmys Corporation LLC, which would focus on the key target element (copper) and equally on the accompanying (silver, cadmium, molybdenum) target elements.

To date, non-ferrous metallurgy has seen no examples of an efficient solution for online monitoring of ores with a particle size of –300 mm and silver and cadmium grades of 1+ ppm by any physical methods on process conveyor belts using suspended ore controlling stations (OCS).

The global OCS market is diverse and offers
- energy dispersive X-ray fluorescence (EDXRF) systems such as OCS STARK (KrasnRados LLC, Krasnoyarsk), OCS-KM (Technoros LLC, Krasnoyarsk), Online Conveyor XRF Analyzer Con X-03 (Baltic Scientific Instruments Ltd, Latvia), OCS ARP-1Ts (Tekhanalitpribor LLC, Moscow);
- Gamma Neutron Activation Assay (PGNAA) OCS such as CB Omni (Thermo Fisher Scientific, Australia), GEOSCAN (Scantech. Australia), NITA II (ScanMin Africa, South Africa), EBA 1-2 CE (ENCE GmbH, Switzerland); OCS based on NIR (near infrared) spectroscopy SpectraFlow Crossbelt (SpectraFlow Analytics Switzerland, Switzerland); OCS based on laser-induced breakdown spectroscopy (LIBS) MAYA-6060 (Laser Detect System - LDS, Israel) [1-5].

Only the EDXRF RCS can be best accommodated within the dimensions of the conveyor galleries at Kazakhmys Corporation LLC processing plants. Positive experience has been demonstrated using EDXRF OCS RLP-3-02 (Geotech LLC, Saint-Petersburg, Russia) at Zhezkazgan concentration plants (ZPP-1 and ZPP-2) since 2014 [6, 7]. During the production operation it was discovered that the OCS-RLP-02 was not capable of clear determination of low silver grades, which cast it out of the ranks of equipment to be included in the program.

The import substitution program dictated that EDXRF OCS RLP-21T (Aspap Geo LLC, Almaty, Kazakhstan) should be chosen as the base unit for the study. OCS RLP-21T was designed specifically to determine low (2+ ppm) silver grades (Fig. 1). The most advanced X-ray tubes, silicon drift detectors, the latest high-speed electronics and powerful software are used in the OCS, which ensured confident determination of silver and cadmium grades of 2+ ppm. This conclusion was made according to the results of bench tests on control powder and finely ground samples at ZPP-1 and ZPP-2.

Fig. 1. OCS RLP-21T.

At ZPP-1 and ZPP-2, ore is received from Zhezkazgan and Zhaman-Aibat deposits boasting higher silver grades compared to ores from other deposits (average grades of 15 ppm).

A much more complicated case is the Balkhash Processing Plant (BPP), which receives ores from Nurkazgan, Sayak Group, Kounrad, Shatyrkol, and Akzhal deposits and also treats waste slags from the Balkhash Copper Smelter (BCS) characterized by a highly complex elemental matrixes for interpretation by X-ray fluorescence method, e.g.: Cu=1.15%, Zn=5.90%, Pb=0.65%, Fe=46.80%. Ores treated at BPP have very low silver grades (usually less than 10 ppm, while Kounrad and Nurkazgan have less than 3 ppm) and a broad range of copper grades (0.2-4%).

Karagaily Processing Plant (KPP) treats ores from Akbastau and Abyz deposits. Nurkazgan processing Plant (NPP) only treats ore from Nurkazgan UG mine (NUGM).

A large number of OCS installation locations and several deposits within the scope of this study dictated the need to solve the problem in two stages. At the first stage of research, OCS-RLP-21T was tested on ore from deposits that are processed at ZPP-1 and ZPP-2. This stage helped identify the true scope of OCS RLP-21T capabilities in terms of sustainable performance on low silver and cadmium grades and recommendations were made on improving the hardware, methodology and software for the OCS RLP-21T to guarantee positive performance of the unit in the second stage (BPP, KPP, NIR).

3 Study results

After completion of the full cycle of bench and industrial tests of the OCS-RLP-21T on conveyors, in October 2016 it was launched on conveyor No. 1T ZhDM-2 (Fig. 2, left), and in January 2017 similar units were installed on conveyors No. 2T ZPP-2 (Fig. 3, right), and No. 1A ZPP-1 (Fig. 4, right) [6-7].

Fig. 2. OCS RLP-21T on conveyors No. 1T and No. 2T ZhDM-2.

The optimal measurement procedure was selected. Single measurements (1 sec) are performed one after another without gaps. grades of copper, zinc, lead and iron were calculated as averages of 20 single measurements; grades of silver, cadmium and molybdenum were the averages of every 40 single measurements.

Fig. 3. OCS RLP-21T on conveyors No. 1A (right) ZhDM-1.

In the course of control sample studies, the influence of the height of OCS suspension on copper and silver grade determination accuracy was evaluated. It was found (within an exposure of 300 sec) that when changing the height of the RCC suspension from 22 to 72 cm, the determined copper and silver grades did not change much: copper was from 0.776 to 0.785%, and silver was from 10.95 to 9.8 ppm, but the measurement errors changed to a much greater extent: error for copper changed from ±0.0088 to ±0.038%, and error for silver changed from ±3.2 to ±18.0 ppm.

Fig. 4. OCS RLP-21T on conveyors No. 2 and No. 2A BPP.

Accounting for the variable ore-OCS gap in the RLP-21T OCS is carried out in two ways: by the MaxBotix MB7067 ultrasonic distance sensor; by the intensity of the scattered radiation of the elements composing the ore on the conveyor belt. MaxBotix MB7067 is the primary way to track the variable ore-PKC clearance. The results of the production operation of the two OCS RLP-21T units in 2019 at ZPP-1 are shown in table 1.

Table 1. The results of the OCS RLP-21T on the conveyor No. 1A ZPP-1 for 2019.

2019	Copper, %			Silver, ppm		
month	Overlfow	OCS	σ, %	Overflow	OCS	σ, %
1	0,91	0,88	3,30	13,351	13,07	2,10
2	0,88	0,87	1,14	10,821	10,792	0,27
3	0,97	0,91	6,19	10,183	9,891	2,87
4	0,97	0,93	4,12	9,860	9,383	4,84
5	0,964	0,926	3,94	9,191	8,83	3,93
6	0,978	0,983	0,51	10,263	9,75	4,97
7	1,071	1,089	1,68	9,70	9,426	2,82
8	1,026	1,080	5,26	8,328	8,755	5,13
9	1,059	1,057	0,19	8,734	8,752	0,21
10	1,024	1,040	1,56	8,274	8,888	7,42
11	1,042	1,056	1,34	8,536	8,512	0,28
12	1,094	1,076	,65	8,666	8,441	2,60
2019	**0,999**	**0,991**	**0,76**	**9,659**	**9,541**	**1,22**

The results of the production operation of the OCS RLP-21T in 2019 at ZPP-2 are shown in table 2.

The first stage of research on the introduction of the RLP-21T OCS was completed successfully and it was decided to move on to the second stage of tests.

All four new OCS RLP-21T units designed for more complex analytical tasks at the BPP and NIR in were equipped the following components: more powerful x-ray tubes with a working voltage of 60 kV; silicon drift detectors (SDD) of a larger area; state-of-the-art high-speed electronics; upgraded software package for new challenging analytical tasks. Two RLP-21T OCS units intended for testing at BPP had to be deprived of the unified calibration of the RLP-21T spectrometer and were switched to include on-object calibration. The desired calibration is selected automatically depending on the

grades of the main elements (as well as iron) and entries in weighing tickets. The remaining two OCS RLP-21T units retained the measurement procedure underpinned by the basic principle of Aspap Geo LLC: x-rayed objects are different in varying ore types with a range of ore processing products – delivered – all using the same calibration.

Table 2. The results of OCS RLP-21T on conveyors No. 1T and No. 2T at ZPP-2 in 2019.

2019	Copper, %			Silver, ppm		
month	Overflow	OCS	σ, %	Overflow	OCS	σ, %
1	0,86	0,82	4,65	11,546	11,848	2,62
2	0,83	0,82	1,20	10,850	11,396	5,03
3	0,81	0,80	1,23	10,732	11,393	6,16
4	0,83	0,81	2,41	12,037	12,257	1,83
5	0,777	0,74	4,76	11,226	11,545	2,84
6	0,835	0,823	1,44	12,95	13,37	3,27
7	0,821	0,825	0,49	13,73	13,923	1,41
8	0,807	0,83	2,85	12,042	12,777	6,10
9	0,820	0,812	0,98	13,037	13,363	2,50
10	0,824	0,813	1,33	14,387	14,952	3,93
11	0,799	0,810	1,38	14,057	14,779	5,14
12	0,831	0,840	1,08	14,332	14,916	4,07
2019	**0,820**	**0,812**	**1,03**	**12,577**	**13,044**	**3,71**

Since zinc is contained in the conveyor belt components, the time intervals on an idle or moving empty belt (as per belt motion sensor readings) were excluded from the data sets.

Before installation on conveyors, all OCS RLP-21T units passed the standard set of bench tests. In this case, sets of calibration samples of ores from each deposit with known chemical compositions for all six elements were used. Each set included three types of samples: powders, roller-crushed ore, and jaw-crushed materials. After each OCS was suspended directly over the respective conveyors, the entire cycle of testing on the samples was repeated respecting the limitation of conveyor idle time availability for testing.

The results of the second stage of studies were as follows:

1. At the BPP OCS RLP-21T installed on the input belt conveyors No. 2 and No. 2A and commissioned on May 4, 2018 (Fig. 4). Detected elements were copper, lead, zinc, silver, cadmium, and iron.

Since July 2018, the railcar test station of the technical control department (TCD) on the KKD 1500/180 cone crusher was decommissioned [8-9].

The results of the production operation of the OCS RLP-21T in 2019 at BPP are shown in table 3.

Over the entire period of OCS operation the following silver grades were recorded in one railway train: maximum – 11.5 ppm (Tastau mine) and 12.3 ppm (waste slag); minimum – 1.9 ppm (Kounrad mine). This is much lower than the level of silver in ores entering ZPP – 1 and ZPP – 2. Thus, for the first time in global practice, EDXRF OCS was able to acurately detect such low silver grades in ores with a grain size of -300 mm.

2. At KPP the OCS RLP-21T unit was installed on conveyor belt No. 4 and commissioned on July 27, 2018 (Fig. 5). The ore size is -50 mm. Target elements are copper, lead, zinc, silver, cadmium, iron [8-9].

Table 3. The results of the OCS RLP-21T on conveyors No. 2 and No. 2A BPP in 2019.

2019	Copper, %			Silver, ppm		
month	Overflow	OCS	σ, %	Overflow	OCS	σ, %
1	1,11	1,13	1,80	4,94	4,32	12,55
2	1,04	1,02	1,92	4,69	4,12	12,15
3	0,92	0,94	2,17	3,26	3,66	12,3
4	0,82	0,8	2,44	3,15	3,56	13,0
5	0,94	0,98	4,26	3,42	3,84	12,3
6	0,99	1,07	8,08	6,06	4,94	18,48
7	0,98	1,07	9,18	6,33	4,19	33,81
8	0,97	1,10	13,4	5,43	4,31	20,71
9	0,84	0,89	5,95	5,47	3,99	27,11
10	0,89	0,97	8,99	5,56	4,07	26,80
11	0,89	0,93	4,49	5,14	3,99	22,37
12	1,00	1,02	2,00	5,22	4,66	10,73
2019	**0,949**	**0,993**	**4,65**	**4,889**	**4,137**	**15,39**

Fig. 5. OCS RLP-21T on conveyor No. 4 KPP.

The following silver contents were recorded in one five-minute measurement: 19.6 ppm (maximum) and 6.5 ppm (minimum). This is another confirmation of efficiency shown by unique methodological and mathematical fragments of the OCS RLP-21T.

3. OCS RLP-21T unit on the main conveyor belt of the Nurkazgan underground mine was put into operation on June 14, 2018 (Fig. 6). Target elements are copper, lead, zinc, silver, cadmium, and iron.

Fig. 6. OCS RLP-21T on the main conveyor of the NPR.

The following silver and molybdenum grades were recorded in one five-minute interval: silver – 7.4 ppm (maximum) and 1.1 ppm (minimum); molybdenum – 0.1370% (maximum) and 0.0011% (minimum) [8-9].

4. In August 2019, the most recent modification of OCS-RLP-21T (the same as at BPP, KPP and NIR) was installed on conveyor No. 1 ZPP-1 (Fig. 2, left) to replace the OCS RLP-3-02 (Fig. 7). For ease of maintenance, this OCS folds the floor at an angle of 90^0 [9].

Fig. 7. OCS RLP-3-02 on conveyor No. 1 at ZPP-1.

The difference between conveyor No. 1 and conveyor No. 1A is that ore flow on conveyor No. 1 is noticeably more narrow than on conveyor No. 1A. Zinc is present in the material of the conveyor belt, so measures had to be taken to reduce the "viewing range" of the OCS RLP-21T. Sensitivity of the EDXRF method decreased and the decrease was compensated through applying 60 kV instead of 50 kV to the X-ray tube.

The results of production operation of the OCS RLP-21T in 2019 on conveyor No. 1 at ZPP-1 are shown in Table 4.

Table 4. The results of the OCS RLP-21T on the conveyor No. 1 ZhOF-1 for 2019.

2019	Copper, %			Silver, ppm		
month	Overflow	OCS	σ, %	Overflow	OCS	σ, %
8	0,638	0,728	14,11	8,700	7,394	15,01
9	0,756	0,800	5,82	11,097	9,352	15,72
10	0,716	0,767	7,12	10,252	9,85	3,92
11	0,746	0,774	3,75	10,824	9,943	8,14
12	0,776	0,803	3,48	11,131	11,592	4,14
2019	**0,726**	**0,774**	**6,61**	**10,401**	**9,626**	**7,45**

The results of the RKS RLP-21T testing on conveyor No. 1 at ZPP-1 are not so successful compared to those from conveyors No. 1A at ZPP-1 or on conveyors No. 1T and No. 2T at ZPP-2. Based on 2019 performance, the calibration of the OCS RLP-21T will be slightly adjusted.

4 Conclusions

1. The unit for online grades monitoring of main (copper, lead, zinc) and related (silver, cadmium, molybdenum) elements in copper-containing polymetallic ores delivered to ZPP-1, ZPP-2, BPP, and KPP was developed, comprehensively tested and commissioned on production scale, and at ore mining facilities. The unit is based on EDXRF OCS RLP-21T manufactured in Kazakhstan. The total of 8 OCS RLP-21T were commissioned.
2. For the first time in Kazakhstan's non-ferrous industry a reliable online system for monitoring coarse -300 mm very low silver, cadmium (1+ ppm) and molybdenum (10+ ppm) grade ores was implemented on process conveyor belts on the scale of a very large mining company (Kazakhmys Corporation LLC). Real prerequisites have been established for the operational management of associated mining of these metals [14].
3. The problem was solved with minimal investments (a number of companies from Australia and South Africa had proposed to achieve this with the help of CSs using the gamma-neutron activation analysis method - PGNAA; the cost of one such OCS exceeded the cost of the eight currently deployed EDXRF CSL RLP-21T units).
4. With the introduction of the OCS, the miners are provided with online information on the quantities of metals and metal grades of the ore delivered to the processing plant during the shift, day and month-to-date, and are now able to promptly make the necessary adjustments to the process of ore and metal mining. The reliable evidence base is available for them to stand their ground in terms of the qualities of ore delivered to the processing plant during redistribution of overflow metal treated through the processing plant in a calendar month.
5. As a result of OCS installation on process conveyors at ore processing plants, the standard quality control testing points on cone crushers were decommissioned: KKD 800/160 (ZPP-1), KKD 1500/1800 (ZPP-2), KKD 1500/180 (BPP) at ZPP-2.
6. Further practical application of the OCS RLP-21T is on conveyors carrying dried copper concentrate to Zhezkazgan Copper Smelter of Kazakhmys Smelting LLC (OCS CON-X from Baltic Scientific Instruments, Latvia is covering the scope at Balkhash Copper Smelter of Kazakhmys Smelting LLC).
7. OCS RLP-21T is used outside of Kazakhstan since 2019 when two OCS RLP-21T units were commissioned at CJSC Silver Magadan (Russia).

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Ways of increase of efficiency of drilling-and-blasting

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Abstract. Results of theoretical researches and industrial experiments on technology of breaking of a massif with use of the artificial screens formed by lumbago of blasthole charges are resulted. In research the technology of breaking of ore by means of the vertical concentrated charges (VCC) on in advance formed screens is offered at underground mining. Possible ways of improvement of technology of working of deposits which will provide reduction of a production cost of ore are considered. The effective variant of a location of chisel developments, charges of the vertical concentrated charges (VCC) and artificial screens in the block is considered. It is analyzed the basic variants of formation of a shielding layer at breaking of ore by fans of deep boreholes and a location of boreholes in the coupled fan. The effective sequence of breaking of ore and necessary parameters of drilling-and-blasting is offered at underground mining. Comparison of results of measurements of granules of metric structure of the crushed mass on experimental sites of an ore mine is considered, analyzed and spent. The method of increase of efficiency of passage of the reflected and broken waves through the screen is offered at ore breaking. The considerable effect from explosion of charges in the presence of zones of unloading is resulted with is artificial they formed screens at massif destruction by the vertical concentrated charges.

1 Introduction

Raw-material base of ore mining branch of Ukraine are deposits of iron ores. Iron an ore treating industry of Ukraine is in a condition of a competition to manufacturer's iron of ore raw materials from other countries. For today Ukraine makes noncompetitive iron ore raw materials of underground mining in comparison with iron ore raw materials of other countries.

On a mass particle of iron it on 4–6 % more low, and behind a mass particle of earth silicon on 11–13% above, than in commodity iron ore which gets on the world market from Brazil, Australia, Sweden and other countries.

But the Ukrainian iron ore raw material holds out a competition at the expense of its lower price. Therefore the decrease of the cost price iron of ore raw materials is the pivotal problem at mining of deposits.

The analysis of the mining literature shows, that scientific operations with effective solutions of the given problem at an underground extraction iron of ore deposits is insufficiently at the present development of scientific and technical progress.

As practice of mining of ore deposits most the item of expenditure in mining shows ore deposit iron there is an ore breaking [1, 2]. It makes 25–30% from the general cost price on the block. Into this article enters: drilling of boreholes, blast holes, an explosive, means of undermining, a charging and undermining of boreholes and other. Cost price decrease under article ore breaking can give considerable economic benefit.

Considerable economy behind this article probably to reach if to lower expenses for drilling and an explosive. Explosive expenses should be connected with quantity of the bared surfaces in the block which is undermined. Usually at ore undermining in the block with one bared surface, or, for example, an interchamber pillar, a roof coal which two have, or even three bared surfaces one is used and too specific quantity of explosives on 1 t ores. It would be expedient to reduce expenses of explosives depending on quantity of the free bared surfaces in the block.

This dependence of specific expenses of an explosive at undermining from quantity of the bared surfaces is described by the known formula

$$q_n = q \cdot \sqrt{\frac{1}{n}}, \text{ kg/t}, \quad (1)$$

where q_n – quantity of an explosive at undermining of a massif with n the bared surfaces, kg/t; q – quantity of an explosive at undermining of a massif with one bared surface, kg/t; n – quantity of the bared surfaces, pieces.

If the bared surface faces broken-down rocks in this case fading of amplitude of waves of stresses there will be something smaller, than in a case with the bared surface of considerable width [3–6].

2 Methods

So, it is necessary to develop, or to improve existing technologies of working of deposits which are

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characterized by smaller indicators of specific expenses of explosives and ore production costs at application of effective breaking by means of the vertical concentrated charges [7–9].

3 Results and discussion

The general interest and scientifically-practical value is represented by a substantiation of breaking by charges VCC on is artificial they formed screens in the block which is undermined.

If instead of the customary bared surface (a surface of the compensatory chamber) there is a screen which represents intensively fissured from a lumbago of fans of boreholes a soil layer in this case the broken ground density will not be above 0,9 density of a massif. Reflexing of waves of stresses from such screen will be less, and absorption of energy of a falling wave considerable.

Breaking of rocks with use of shielding layers can be applied in conditions when the ore hardness and adjacent strata makes from above 10 on M. M. Protodyakonov's scale. With use of shielding layers in ores a fortress it is less than considerable researches of application of breaking of rocks 10 on M. M. Protodyakonov's scale were not spent, as in such ores and soils it is possible to use any other cheaper ways of breaking and types of explosives.

Let's consider what effect from explosion action will occur at it is artificial they formed screen from a lumbago of fans of boreholes in a block massif (fig. 1).

At simultaneous undermining of one or two fans of boreholes in a plane of their location opposite directed distribution of cramping stresses from action of adjacent charges takes place. At their meeting in 3–4 times pressure raises, besides in a plane of a location of boreholes transformation of cramping stresses in stretching takes place that leads to cracking between charges. It sharply increases deficiency of a rock mass to the screen which will lead to change of its physical properties.

The most effective way of initiation of wells in a fan is counter initiation. At such way of initiation the best cracking in a zone between wells is provided, that considerably improves reflecting ability of shielding layers. In a fan, drilled on interchamber pillar boundary it is necessary to initiate wells a return method. It allows reducing in two and more times sizing of the maximum stresses on a free surface of a pillar and by that not to break its integrity. The shielding layer prevents distribution of waves of stresses deep into a massif. The wave of a stress formed from explosion of a charge, having reached boundary of a shielding layer partially (18 %) comes back in a broken massif that improves quality of crushing, partially (74 %) are absorbed by a layer of broken ground of a shielding layer and only 8 % of energy of a wave of a stress extend in an edge massif.

Except improvement of quality of crushing of the broken massif, shielding layer in 2–3 and more times reduce size of seismic fluctuations that allows to protect objects from destruction and to increase volume of simultaneously blasted out explosive without excess of admissible values of seismic fluctuations for protected objects.

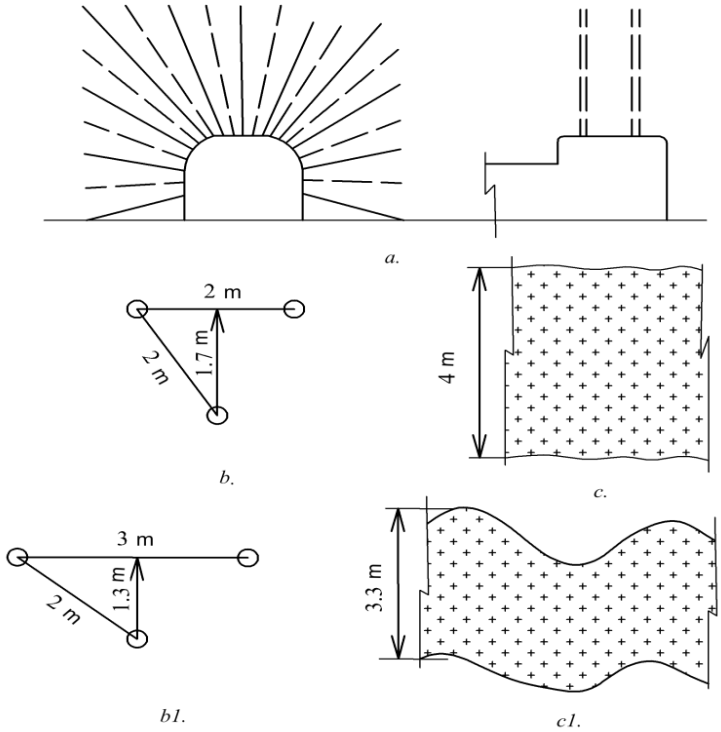

Fig. 1. Variant of formation of a shielding layer: *a* – the scheme of drilling out of fans of deep boreholes Ø105 mm; *b, b1* – the scheme of a location of boreholes in the coupled fan; *c, c1* – the form of a shielding layer after explosion of boreholes.

Presence of a shielding layer allows to destroy a massif aside opposite to a breaking direction (deep into a massif) on size of 0,7·W (burdens).

The fans of deep wells drilled for formation of shielding layers, are drilled out on sides of blasted out layers.

The side of a blasted out layer which is simultaneously a surface of funnels of release, is not drilled out by fans of deep wells. Before explosion VCC the turn of cone raises, except a cone raise located under VCC is made. The turn of these cone raises is carried out with slowing-down after explosion VCC. Formed from a turn of cone raises the bared surface is a shielding layer. If the blasted out layer at floor-chamber mining method or a block caving, collapses two VCC, located on a vertical first of all it is blasted out overlying VCC and from mile by second slowing-down undelaying VCC.

If power of a deposit is that, that the across the strike settles down two or blasted more out layer destruction of these layers is carried out in sequence from a trailing side to the lying. Before destruction of the subsequent blasted out layer release of the destroyed ore of the previous blasted out layer with a rocky pillow on the bottom is made.

Wave resistance of a massif and wave resistance of the screen differ in 2,5 times. Considering, that a stress at explosion of the concentrated charge (VCC) decrease in inverse proportion to a distance cube, and from a borehole column charge in inverse proportion to a distance square the distance from a charge to the screen will be equaled

$$W_{en} = \sqrt{\frac{m-1}{m+1}} \cdot W, W_{en} = 0{,}65 \cdot W, \text{ m}, \qquad (2)$$

$$W_{es} = \sqrt[3]{\frac{m-1}{m+1}} \cdot W, W_{es} = 0{,}75 \cdot W, \text{ m}, \qquad (3)$$

where W_{en} – distance from a column charge to the screen, m; W_{es} – distance from the concentrated charge to the screen, m; m – the relation of wave resistance of massif R_1 and screen R_2; (m=R_1 / R_2); W – a burden of breaking of a massif, m.

It means, that for reception of such stresses, as well as at reflexing from a free surface, the screen is necessary for forming on distance from a charge which is equaled 0,65–0,75W (Fig. 2).

Equality of time of passage of a wave of tension from the screen to a charge and run in the screen of a wave of compression and tension is a condition of the maximum refracting ability of the screen

$$\frac{W_e}{C_м} = \frac{2\Delta_{max}}{C_e}, \qquad (4)$$

where $C_м$, C_e – speed of a sound in a massif and the screen in broken soils accordingly; m/s; Δ_{max} – the maximum width of the screen, m; W_e – a thickness of a layer of ore from a charge to the screen, m.

So,

$$\Delta_{max} = 0{,}5 \cdot \frac{C_e}{C_м} \cdot W_e. \qquad (5)$$

This relation is customary C_e / $C_м$=0,65–0,75, then Δ_{max}≈(0,3–0,4)W_e or for a column charge Δ_{max}=(0,2–0,26)W, for the concentrated charge Δ_{max}=(0,23–0,3)W.

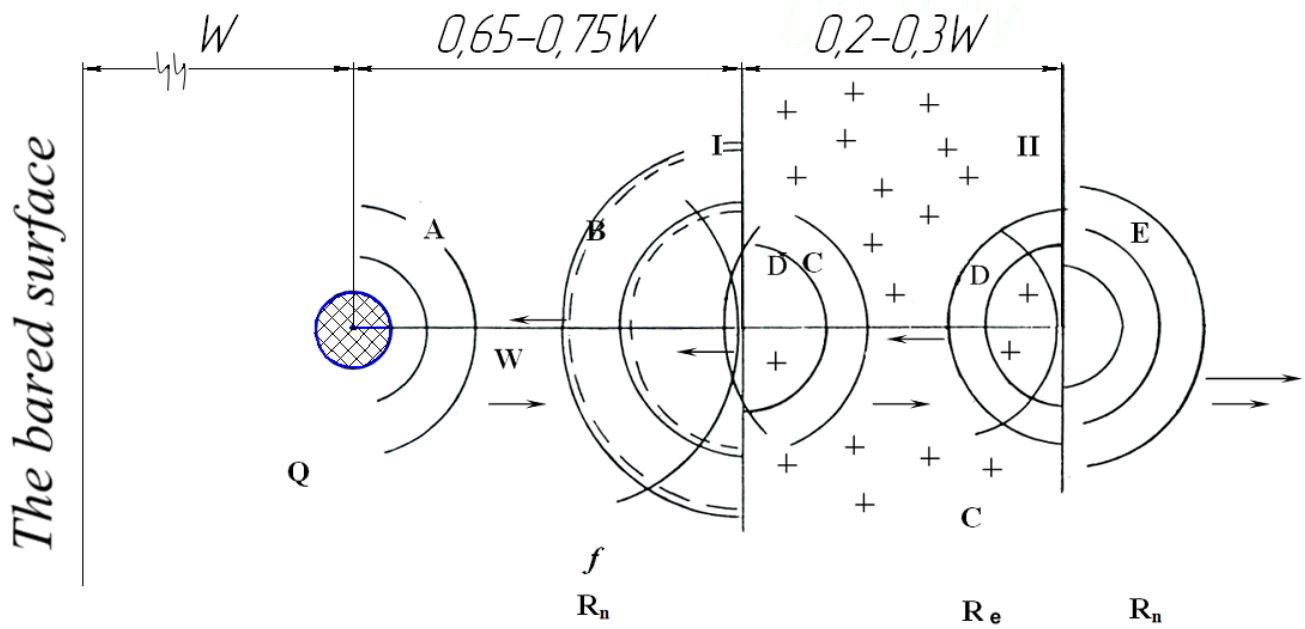

Fig. 2 Scheme of passage of the reflected and broken waves through the screen: *A* – a wave of compression from charge *Q; B* – a wave which is reflected from a wall I (a tension wave); *C* – a wave of compression which has driven through a wall I; *D* – the wave of compression which was reflected from a wall II, has turned to a wave of tension and has driven through a wall I in the side of charge *Q*; *E* – a wave of compression which has driven through walls I and II towards a massif.

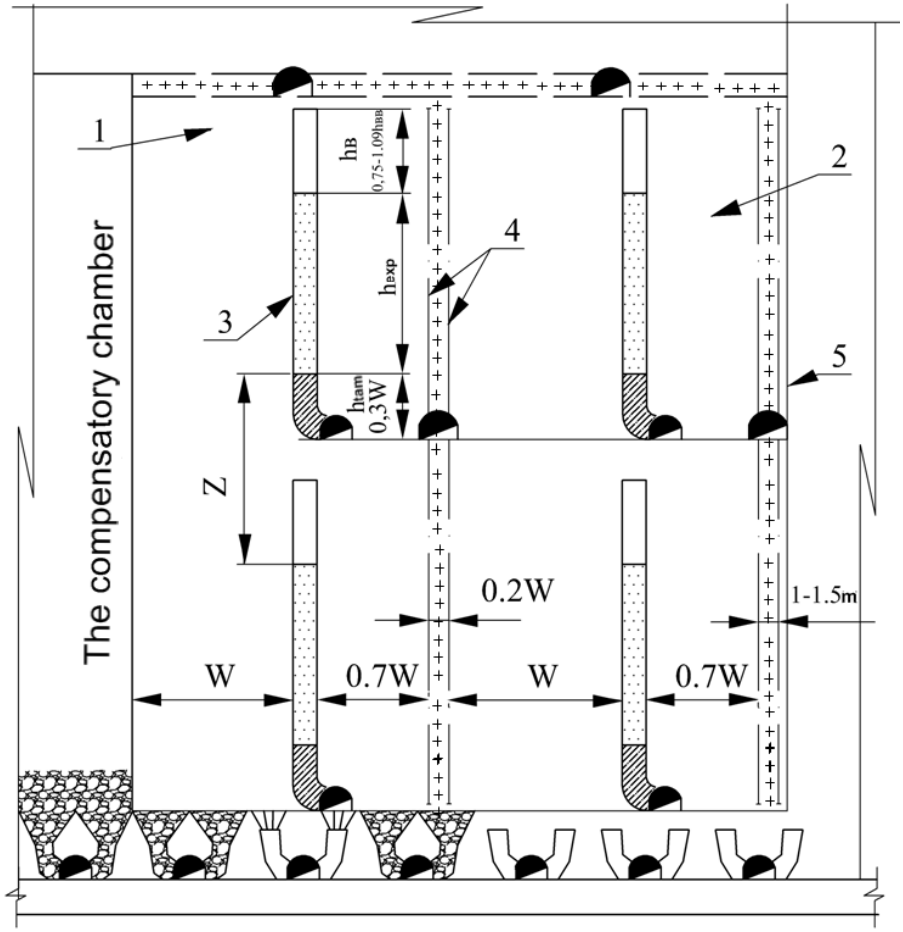

Fig. 3. A location of charges VCC and artificial screens in the block: 1 – a layer which is undermined the first turn; 2 – layer which is undermined the second turn; 3 – VCC; 4 – the coupled fan of deep boreholes for formation of a shielding layer; 5 – boundary with pillar of the next chamber.

As energy of waves of stresses is proportional to amplitude square reflected energy of waves of stresses will be equaled

$$\frac{\sigma_{ref}}{\sigma_м} = \left(\frac{m-1}{m+1}\right)^2 = 0{,}18, \qquad (6)$$

It means, that the screen from the rocks mentioned by explosion breaks a maximum of 18% of energy of a falling wave.

In this case, when on a way of waves of a stress the screen the formula 1 will look like is placed

$$q_n = q \cdot \sqrt{1/n_e} \cdot 1{,}22, \text{ kg/t.} \qquad (7)$$

Formation of artificial screens is expedient for applying, if the massif is undermined by charges VCC and burden breakings reaches 20 and more meters. In this case having created the screen, probably, considerably to increase volume of soil which is broken and to reduce, thus, explosive expenses. The soil volume increases because the massif collapses, both towards the bared surface, and towards the screen.

Using technology of shielding of shock waves, probably to fulfill thick deposits of iron ores on the technology shown on (Fig. 3).

The essence of the above-stated technology of working of deposits of strong ores and magnetite quartzite's consists in the following: 1) the basic massif of the block is broken by the vertical concentrated charges of explosive (VCC); 2) charges of the pseudo-spherical form (the relation of height of a charge to its diameter makes 5÷8) and is powerful 10–30 and more tons. Preliminary before explosion VCC shielding layers on all sides of the broken block (not having an exposure) are formed.

VCC settles down in a place of the explosive block which is the center of equally effective action of explosion. The stresses arising on a surface of the shielding layer and the bared surface of the compensatory chamber, from explosion VCC located in the center of equally effective action of explosion are equal.

The massif of the fulfilled block is divided by shielding layers into separate sites and each of them blasted out by one or two vertical concentrated charges of explosive (VCC), generated in vertical or horizontal workings. The shielding layer represents the destroyed layer of soil in the thickness 0,2·W, located on the verge of the broken layer representing a parallelepiped in the sizes 40×30×30 m (roughly).

On distance 0,7·W the filter behind all sides of the block which is broken except for the compensatory chamber and the block bottom is formed. In this case the volume of broken soil one charge VCC in the block will

increase almost twice, and expenses for breaking too will be reduced twice.

Breaking of rocks with use of shielding layers has been applied on opencasts of Buurdinsky and Hajdarkansky ore mines of Kirghizia in granite porphyrites by durability 10–12, chalkstones and jasperoid durability 10–14 on M. M. Protodyakonov's scale [10, 11]. The massif of soils was undermined by four numbers of boreholes. Last number of boreholes was undermined by the first, having created, thus, the screen from intensively fissured and partially broken grounds. Numbers of boreholes on soil loosening were then undermined. At these explosions the volume of broken ore has increased, and expenses of explosives for breaking have decreased for 20–25 % and the average size of a piece has decreased for 20%.

Change of all indicators on the average on 20–25% specifies in direct correlation dependence between increase of efficiency of the explosion, which directly proportional to quantity put aside the basic volume of destruction of energy of waves of a stress (25%) and size of an indicator of specific expenses of explosives. A penultimate number of boreholes have destroyed completely a layer towards the bared surface and towards a shielding layer.

Efficiency of application of shielding of waves of stresses at the expense of preliminary created screen [12] has been checked up on career of Inguletsky GOK.

In mining practice the way of separation of a broken massif is known for a method of preliminary formation of cracks. This method has a number of lacks. Formation of cracks is carried out by explosion of weak charges, in 6–7 times it is less, than a customary blasthole charge. The distance between wells in 3 times is less, than at breaking ground. However to create a crack at explosion of such charges not always it is possible, as there should be favorable conditions: the monolithic massif or a bedding of layers of ore coincides with a line of some the drilled wells. Besides, explosion of weak charges is not capable to form a crack. In a case if the crack nevertheless is formed, it will be insignificant width; therefore it cannot effectively shield a wave of stresses. The big share of energy leaves in a massif, therefore to reduce expenses for drilling-and-blasting's it is not obviously possible.

For screen formation on boundary of the block which is undermined, last number of boreholes was charged by charges of explosives in volume on 30% less than customary charges of crushing. Last number of boreholes in the block was undermined in advance in relation to the second rows of boreholes (Fig. 4). At an instantaneous blasting of blasthole charges of such power the broken ground layer between the block and a massif is formed at any direction of beddings. Under such scheme of undermining the chopped ability of the screen which was formed, high enough. First row charges (at four numbers in the block) receive 12 % of energy of a reflected wave, the second row – 25 % of energy of a reflected wave, the third row – 50 % of energy of a reflected wave in addition to the basic energy of explosion.

Experiments have been spent in blocks: 30 – hor. 150 m; 804 – hor. 135 m; 95 – hor. 165 m; 93 – hor. 105 m; 105 – hor. 255 m. Blocks have been presented by soils durability 17–18 behind M. M. Protodyakonov's scale. In blocks it has been drilled on 4 numbers of boreholes. The distance between wells in a number did not change and made 6,5 m. Between numbers of boreholes distance has been increased by 1 m. Distance between boreholes of last number has been reduced by 0,5 m. Last number of wells has been blasted out in advance 100 msec.

Acoustic rigidity of a massif of the screen was approximately in 2,5 times less, than a massif. It modeled screening of waves of stresses for conditions of underground breaking. Undermining of charges carried out under the scheme presented on (Fig. 4).

For definition of quality of crushing of a massif measurements of granules of metric structure of the shattered mass on experimental sites of horizons have been executed 75 and 120 m. For comparison have been made measurements of granules of metric structure at ore undermining on customary technology in similar soils on horizons 95 m. Results of measurement (average values) are resulted in (table 1).

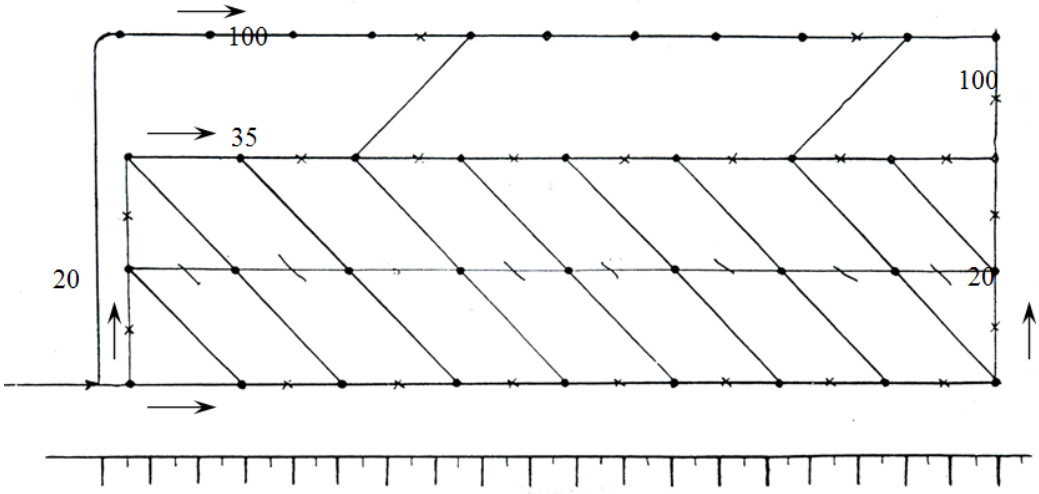

Fig. 4. The scheme of undermining of the block in advance boreholes of last number.

Table 1. Granules of metric structure of broken mined rock on research and control sites.

Site where were spent measurement	Fraction, mm					
	-100	100-200	200-300	300-400	>400	d_{ave}
Research sites (75 m, 120 m)	73,2	9,3	10,5	1,8	5,8	123
Control sites (95 m)	35,7	4,1	14,7	13,3	32,2	360

Improvement of quality of crushing of ore in the block testifies to increase in energy which is spent for the crushing, received for the account of reflexing of waves of stresses from a shielding layer.

Results of measurements of granules of metric structure show, that, despite a decrease of the expense of an explosive quality of crushing on experimental sites has considerably improved. Diameter of an average piece has decreased three times. Uniformity of crushing has essentially grown: the exit of fraction of a class - 100 mm has grown twice, and the exit of fraction of a class more than 400 mm has decreased in 6 times.

As a result of experiment it has been broken 552 thousand m^3 ores, it is saved 157,9 t explosives. The general economic benefit in the prices of 2006 has made 264,7 thousand UAH. Including: from a decrease of expenses of explosives – 229,4 thousand UAH and from a decrease of volume of drillings – 35,3 thousand UAH.

4 Conclusions

According to Yu.P. Kaplenko researches [13, 14] the boundary of section of zones of unloading and the raised cramping stresses is the screen which breaks waves of stresses. Refracting ability of the screen that above, than is more difference in absolute sizes of stresses operating in specified zones. The customary massif which has no unloading zones, at explosion of blasthole charges caves in in the area of a location of boreholes. In the presence of unloading zones there is a shielding of waves of compression and their reflexing towards a charge to their transformation to waves of extension at the expense of what volume of broken soils increases by the same quantity of explosives in 1,6 times.

Such conclusions prove to be true supervision by results of massif breaking magnetite quartzite's on at Ordzhonikidze mine in the block + 8 axes charges VCC. In this block there were unloading zones therefore at explosion of charges on distance burden of 12–16 m breaking to the deep a massif made 5–6 m, and sometimes 10–12 m [15].

Considering such effect from explosion of a charge in the presence of an unloading zone it is expedient to form it is artificial screens especially at destruction of a massif by charges VCC.

Thus reduction of a production cost of ore can be reached at the expense of reduction of expenses of an explosive in the presence of the bared surfaces, or artificial formation of filters.

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The study of the collapse zone by remote methods

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Abstract. The aim of the research is to choose an effective remote method for surveying the area located above the space mined by underground mining. Often in separate sections of these territories funnels and dips are formed that do not allow the use of methods with finding the performer directly at these potentially dangerous sites. The research methodology is based on the implementation of survey work in the territory of the Ordzhonikidze mine, where underground mining is influencing the state of the ground surface and buildings. In this case, various remote survey methods were used. An analysis of the results of the survey work made it possible to determine the most effective method for studying dangerous areas in which horizontal and vertical deformations are observed. As a result of research, special attention was paid to the use of modern remote sensing methods for the territory of the mine. As a result of the analysis of the survey using remote methods, the expediency of applying the method of terrestrial stereo survey is determined, which has the necessary accuracy, and at the same time it is quite operational. The scientific novelty of the obtained results lies in the fact that the effectiveness of the use of ground-based digital stereo survey for studying the deformations of the ground surface and objects located in the mine and adjacent areas that are undermined by underground mining has been proved. The optimal conditions for performing stereo survey of the ground surface and objects of these territories are determined, and a scheme for performing the binding of survey stations is selected. The practical significance of the research is to study the deformations of the ground surface and buildings on the mine territory and adjacent areas, terrestrial digital stereo survey was used, which made it possible to quickly determine horizontal and vertical deformations for a large number of points with the necessary accuracy.

Introduction

The study of deformations of the ground surface and objects is an important task that many scientists and practitioners are involved in [1-5]. With the improvement of surveying and geodetic instruments and software for them, the level of research is being increased [6].

To increase the stability of underground mine workings, effective development systems are developed and implemented, which allows to increase the safety of mining operations and to ensure minimal impact on the ground surface and objects located on it [7,8].

The mine surveying service of the mining enterprise constantly monitors the deformations to which the ground surface and structures on it are exposed due to underworking by their mining operations. In coal deposits, surface deformations are characterized by insignificant values – millimeters, and in the development of ore deposits, their sizes can reach meters. It is known that such deformations often form zones of funnels, terraces, cracks, and smooth movement. The performed studies are devoted to issues of remote monitoring of the funnel zone and observations of the stability of the slopes of the formed failures, using the example of the Ordzhonikidze mine, where in 2010 the collapse was accompanied by the formation of a funnel with an area of 17 hectares.

1 Analysis of remote deformation observation methods

Undoubtedly, the method that gives the most comprehensive information is aerosurveying, but it is not sufficiently informative in the study of vertical slopes [9-11]. Therefore, other remote methods can additionally be used:

- visual inspection;
- use of reflectorless total stations;
- laser scanning;
- scanning based on the use of interferometry;
- ground photogrammetric survey.

Visual inspection is an important priority measure, however, even the use of magnifying optics can only determine the fact of the most significant deformations in the form of cracks and landslides, but it does not make it possible to determine the metric characteristics of the processes. It is the detection of cracks during visual inspection that justifies the implementation of further instrumental studies. Today, from a distance of 650-700 meters visually determine the nature, size and dynamics

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of deformations, even approximately, it seems impossible.

Reflectorless total station is the simplest method that does not require special training and can be performed by an ordinary mine surveyor of a mining enterprise. 10 years ago, electronic total stations with a reflectorless mode up to 1000 m were very expensive and therefore rare. But by the time of the collapse of 2010, the surveying service of the Central GOK had a similar Topcon GPT-3000 device for operation. The first studies of the danger zone in the Ordzhonikidze mine started almost immediately after the collapse, and were performed by this total station by specialists of the mine surveying department of the plant, together with the researchers of the mine surveying department of Kryvyi Rih National University. The use of electronic total stations at the mining enterprises of Krivbass has its own specifics. Dark rocks absorb the rays strongly, and the total station, with a passport value of the reflectorless mode of 1000 meters, actually measures the distance up to 600-650 meters. Naturally, this is not about the characteristics of the device or its malfunction, but about the influence of rocks on the measuring process. This total station without any problems measures the distance to bright objects, for example, to a white wall or a light strip on a chimney at a distance of 980 meters, although it consumes a huge amount of energy, which significantly reduces the battery life. The decrease in the range of the reflectorless mode introduced its own corrections into the observation program, namely, it contributed to an increase in the number of points of polygonometric moves, from the points of which the survey was directly performed. The binding of polygon moves was carried out to the points of the state geodetic network of this region, which are outside the zone of influence of mining operations.

Using the reflectorless mode of the total station, for several days of work the coordinates of 332 points were determined, the total number of which includes not only reference points, but also points of polygonometric moves (Fig. 1, 2).

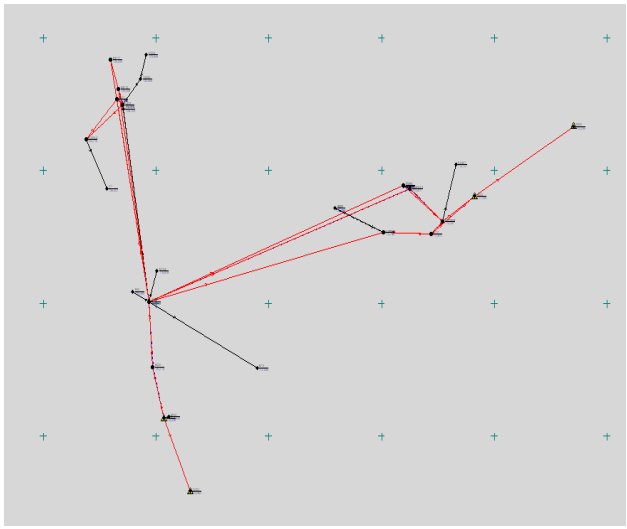

Fig. 1. The scheme of binding moves.

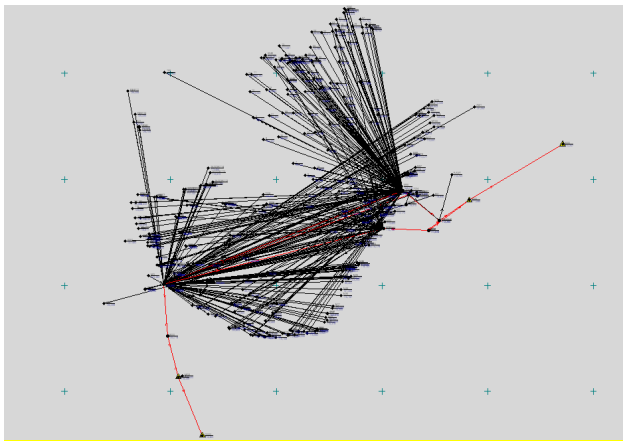

Fig. 2. The scheme of surveying using a reflectorless total station.

As a result of studies, it was confirmed that the use of the method of reflectorless total station in the quarry has significant disadvantages: the presence of a large number of dead zones; the inability to do surveying work in some areas because of the danger of being on them or because of the presence of dense vegetation.

Also a remote method is laser scanning. Laser scanners at the time of the release of the crow in 2010 had a high cost and, at the same time, parameters that did not allow such observations to be performed. It is worth noting that the above disadvantage of reflectorless total station - signal absorption by dark rocks, is equally true for laser scanners. Therefore, for such a survey, you need to have a scanner with a range of at least 1500 meters. Such devices are rare and quite expensive today. In addition, the use of scanners impedes the availability of vegetation. For these reasons, laser sanitization was not used to study the collapse zone and adjacent territories.

It is known that scanning based on the use of interferometry is also a remote surveying method [12]. This method has high accuracy (up to 0.1 mm) in the study of open pits and dumps by comparing two surveys for different dates, but is not applicable for this survey. This technology is very promising and will certainly find application in the mining enterprises of Krivbass, but at the moment its application is complicated by the high cost of equipment and the need for constant protection.

The next of the methods under consideration, which has become the main one along with reflectorless total station, is the method of terrestrial stereotopographic survey. It is worth noting that for this area much later aerial surveys were performed, the results of which almost coincided with the ground. Based on its results, sections were added for which it was impossible to shoot using other methods.

Stereotopographic survey over the past ten years has become completely different. The development of terrestrial stereotopographic surveys in Kryvyi Rih quarries has had its ups and downs. This method is very popular in the seventies of the twentieth century, was practically no longer used in the mid-eighties and early nineties. There were many objective and subjective reasons for this, one of which was the physical and moral obsolescence of filming cameras and

photogrammetric instruments for processing images. An important reason is the transition period in the development of Ukraine, which was characterized by the collapse of all economic relations and the decline of industry.

Stereotopographic survey in Ukraine acquired a new life with the advent and development of the digital photogrammetric station "Delta" and the software product Digitals, produced by GNPP "Analytics" and LLC "Geosystem". It should be remembered that in the Russian Federation at least three digital photogrammetric stations, such as Photomod, Talka and military developments, were also developed. But they were not widespread through an inflexible pricing policy or focus on the military-industrial complex. Therefore, with the acquisition in 2003 of the DFS "Delta" digital camera and in 2005 the EOS 350D digital SLR camera began a new but already digital ground-based stereotopographic survey. In the second decade of the 21st century, there was another improvement related to the emergence of such software products as Pix4d, Photoscan, etc.

2 Research of simultaneous surveying

The need to have certain initial data for orienting the images and the fundamental difference in the obtained results of their processing often complicate the modern digital processing of images of old surveying. The difference is observed in many ways: in the ways of performing the necessary snapping to the image; in the number of survey stations, for example, before there were enough using two stations but now, by using of modern methods, they need more than three; in the need for GPS-snapping to the images. You can manually enter GPS tags in the EXIF data of images, but it will take a lot of time, for example, for 250 images to enter GPS coordinates. Therefore, the combination of new and old surveying in plan is very painstaking work. But the determination of the necessary data on the position of multiple points of terrain or object at one physical moment and the possibility of using them after a considerable period of time is one of the main advantages of photogrammetry.

The pictures were taken for the research of the collapse zone for the surveying dates of August 27, 2010 and July 31, 2019. The survey for August 27, 2010 consisted of 142 eight-megapixel images, of which 11 stereopairs were formed, and the rest of the images were used for the photo documentation of the terrain. The coverage area by stereo pairs is shown in Figure 3.

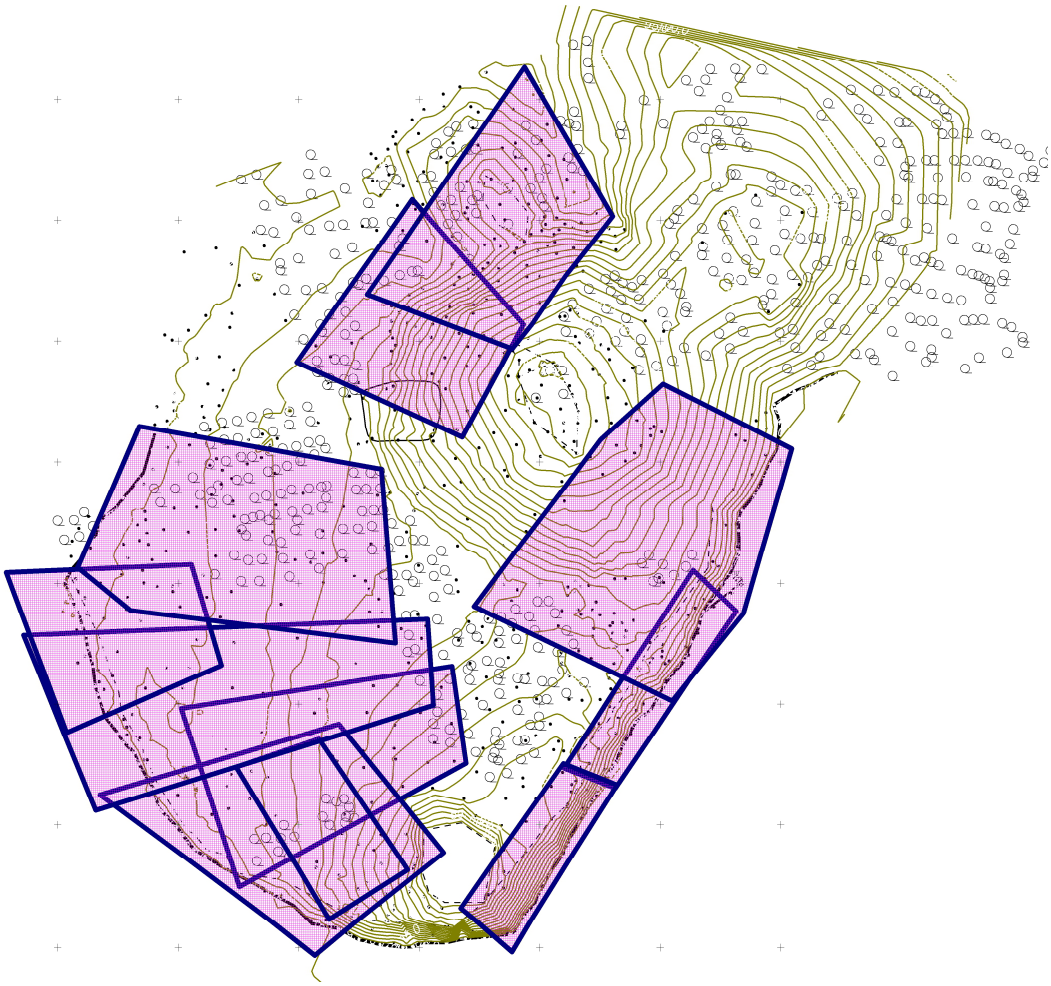

Fig. 3. The terrain coverage with stereopairs surveying for the date of August 27, 2010.

As can be seen from the above scheme of covering the terrain with stereopairs, with an object area of 380,722 m^2, 196,412 m^2 was covered with stereopairs, which is almost 52% of the total area. The accuracy of the planned position of the points due to errors in the external orientation of the stereopairs ranged from 0.01 m to 0.20 m, which meets the requirements of the instructions for performing surveys performed for quarries, that is for the researched object.

Archival pictures of 2010 at that time met the requirements of stereotographic surveys, but preparing them for Pix4D or Agisoft Metashape software products took considerable time. When preparing the 2010 survey data for processing according to the program, most of the time was required to determine the coefficients needed to convert the coordinates from the conventional mine coordinate system to the given one. This is necessary to bring the coordinates of the points of the survey justification to a single coordinate system. For this purpose, three points were coordinated at the industrial site using the Topcon GPS receiver in the static mode and the coordinates of the points Ct1, Ct2, Ar1 and D1 were determined using the polar method from two points 92 and RPC0. Coordinates 91, 92 and K1 are determined with an accuracy of 3mm in plan and 5mm in height. Measurements at steps 92 and RPC0 were performed with a Sokkia SET630R total station in reflectorless mode. The errors in determining the coordinates of the points Ct1, Ct2, Ar1 and D1 ranged from 15 mm to 30mm in the planned position and up to 30 mm in height. The choice of points Ct1, Ct2, Ar1, D1 was not accidental – these are practically the only contours that have remained unchanged for nine years and were recognized with high accuracy in the images for the start and end dates of the surveys (Fig. 4). The presence of green spaces greatly complicated the search for points that would be accurately recognized in the images for both dates.

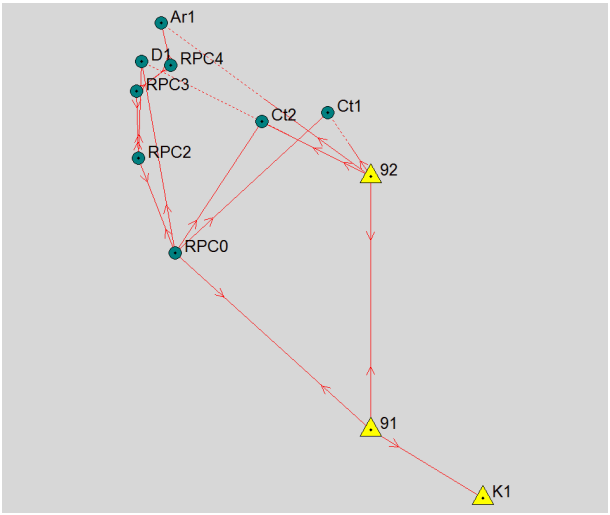

Fig. 4. The scheme of the points of reference and surveying justification.

As a result of processing the pictures taken in 2019 using the Pix4d program, the following errors in the position of the control points were obtained: along the X axis, not more than 139mm; along the Y axis – 138 mm; along Z – no more than 33 mm (Table 1).

Table 1. The accuracy of determining the coordinates of control points according to the survey in 2019.

GCP Name	Error X, m	Error Y, m	Error Z, m	Verified/ Marked
1 (3D)	-0.029	-0.054	0.001	76/78
2 (3D)	-0.071	-0.077	0.001	77/77
5 (3D)	0.005	-0.039	0.032	78/78
7 (3D)	-0.037	0.007	0.018	53/53
8 (3D)	0.016	-0.171	-0.007	53/53
9 (3D)	-0.041	0.151	0.021	29/35
10 (3D)	0.126	0.062	-0.006	33/38
11 (3D)	-0.024	-0.025	-0.005	53/53
13 (3D)	0.076	-0.038	0.054	56/56
16 (3D)	-0.072	-0.060	0.011	6 69
17 (3D)	0.139	0.138	-0.033	61/62
18 (3D)	0.014	0.050	-0.027	47/47
19 (3D)	-0.062	-0.142	0.006	44/46
20 (3D)	0.130	0.114	0.029	56/58
21 (3D)	0.043	-0.103	0.070	70/70
22 (3D)	-0.136	0.078	-0.093	57/57
24 (3D)	-0.120	0.033	-0.044	54/55

The 2010 survey is characterized by a significantly smaller number of images and identifications, and the standard errors are in the range of 5 mm to 150 mm (Table 2).

Table 2. The accuracy of determining the coordinates of control points according to the 2010 survey.

GCP Name	Error X, m	Error Y, m	Error Z, m	Verified/ Marked
1 (3D)	0.135	0.228	-0.049	14/14
2 (3D)	-0.031	-0.032	0.049	14/14
m3 (3D)	0.107	0.020	-0.046	15/17
m12 (3D)	-0.147	0.044	-0.053	10/10
m11 (3D)	-0.118	0.053	0.106	18/18
m4 (3D)	0.073	-0.546	-0.063	17/17
7022 (3D)	0.002	-0.002	0.108	17/17

The points of the surveying object were referenced using GPS Receiver GP-E2 in the WGS 84 coordinate system (EGM 96 Geoid), and the identities were referenced in the Pulkovo 1942 / Gauss-Kruger zone 6 coordinate system (EGM 96 Geoid) by three-point direct intersection.

3 Determination of deformations from the results of processing surveys for different dates

To reduce the errors in determining the position of the points, the 2010 survey was divided into two parts – left and right, which were processed separately. Figure 5 shows a digital model in the form of a point cloud based on the results of the survey in 2019, and Figure 6 presents a digital model in the form of a point cloud according to the results of the 2010 survey.

The diagrams were constructed according to the results of processing the survey data characterizing the magnitude of the deformation of the pit side along three

(X, Y, Z) or two (X, Y) axes (Fig. 7). The blue color shows the areas with minor changes – from 0.01 m to 0.10 m, and shades of green show the areas with strains from 4m to 6m (the shade of green depends on the amount of deformation). The yellow and red colors show a deformation of more than 8 meters.

Figure 8 shows in different colors the strains obtained at the 2010 survey date. Analysis of the color change led to the conclusion that the deformation is concentrated in four zone.

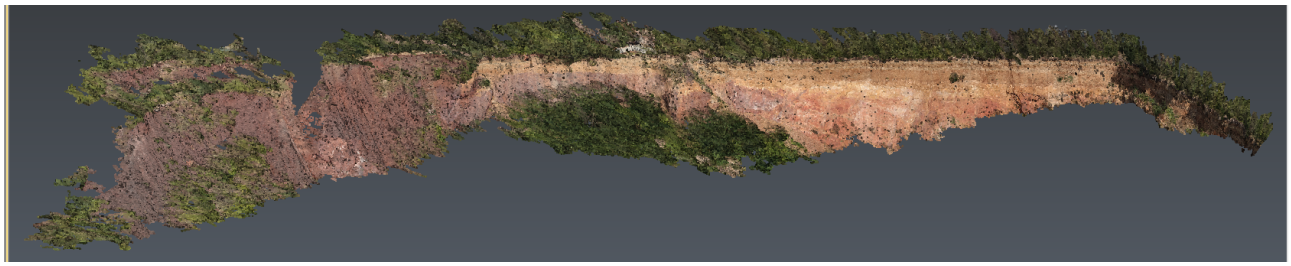

Fig. 5. The digital model created by the results of surveying in 2019.

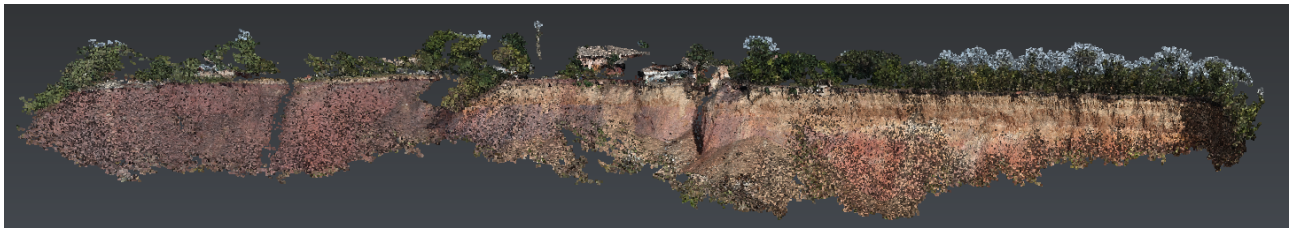

Fig. 6. The digital model created by the results of surveying in 2010.

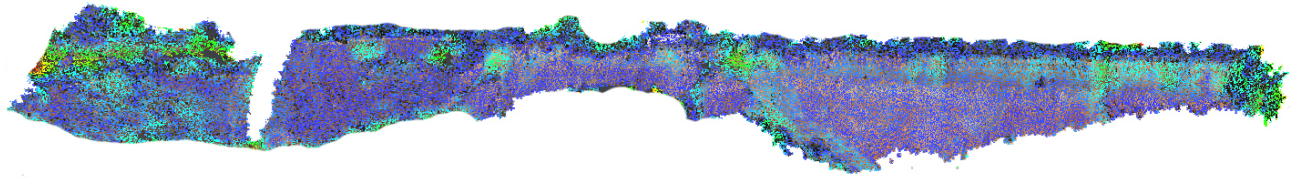

Fig. 7. The deformation of points on the side of the quarry according to the survey in 2019.

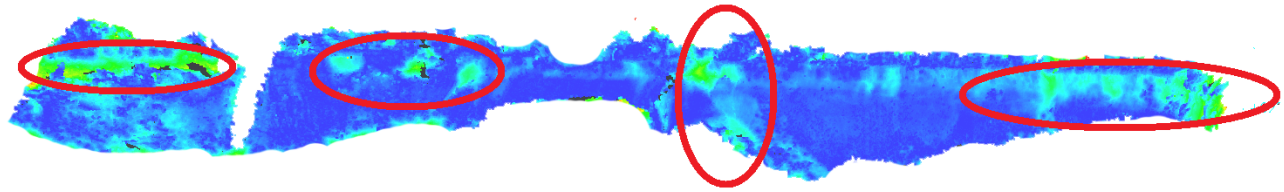

Fig. 8. Zones of maximum deformations.

a *b*

Fig. 9. Sites of the studied second (a) and third (b) zones.

The first zone characterizes the sliding of the side with the formation of the approach. From the mine site, on the profile line adjacent to this zone, strains of up to 1000 mm in plan and 1500 mm in height were observed. Such deformations in magnitude led to significant changes in the surface, and for safety reasons the territory was fenced. Therefore, further observations are carried out only by remote methods.

The second zone combines three areas of rock mass scree with dimensions of about 15 m x 10 m x 5 m, which occurred due to the flattening of an almost vertical side. The analysis showed that the deformation is facilitated by the geological structure of the site, as shown in the image of this site (Fig. 9*a*). The site is composed of bulk rather than rock formations.

The third zone is the site with the most large-scale changes. In this area, the promotion of the crow zone is the most significant and has affected buildings and structures. The site is composed of rocks. No cracks were observed on the site in 2010 (Fig. 9*b*), and in 2019 a large number of them appeared, which indicates active processes and array stress. Therefore, it was this area that was investigated in more detail. From the industrial site, profile lines were laid on this site to monitor the condition of the mountain massif and predict possible collapses.

The fourth zone is the epicenter of the funnel, so increasing it by 5 meters inland is logical. But only the upper layer underwent a change to a depth of 5-8 meters, bedrock is characterized by sufficient stability and a constant position for 9 years of observation.

The most efficient and accurate method for such studies can be considered laser scanning. To perform research on this object, a laser scanner with a range of 1 km is required. The performed studies have led to the conclusion that it is advisable to use ground-based digital photogrammetry for this method, which can replace laser scanning, and will also make it possible to assess the reliability of the results. Two surveys were performed in 2019 for this with an interval of seven days. A short interval between surveying made it possible to use the same points as signs. It was found that under almost identical surveying conditions, the errors of the initial data can be neglected. With sufficient accuracy (3-5 cm), a uniformly blue surface of changes is observed.

Surveying for the date of August 21, 2019 was performed from 11 survey stations that were selected with the fulfillment of the security conditions for the work of the performer (Fig. 10). The selected observation conditions did not allow us to arrange the bases of surveying perpendicular to the object. Therefore, the pictures were taken with a significant bevel to the right (more than 600), which negatively affected the accuracy of the results.

Fig. 10. The scheme of the surveying bases location.

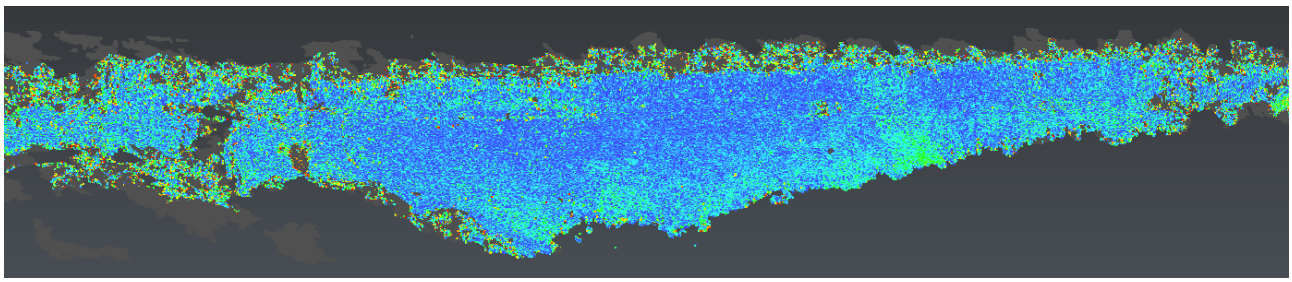

Fig. 11. The position of points with different errors in determining spatial coordinates.

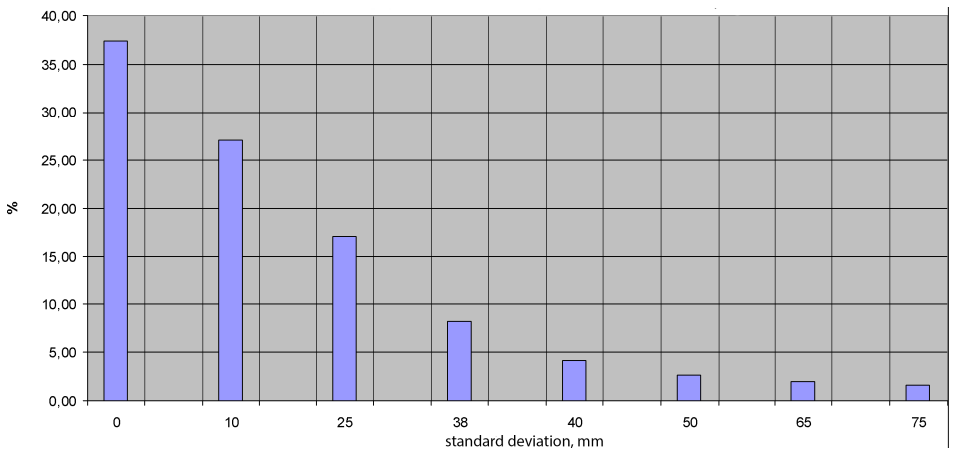

Fig. 12. The distributions of errors in determining the position of points.

The above figure characterizes the accuracy of determining the position of points based on the results of ground-based stereo surveys in the study of slope deformations. In the figure, the blue color corresponds to the studied points, which have a complete coincidence of the spatial position for two dates with an accuracy of 0 mm to 10 mm, which is 37.4% of the total number of points. The number of points whose spatial position coincides over two dates with an accuracy of 10 to 25 mm is 27.0%. The graph (Fig. 12) shows data on the number of points in percent, the accuracy of determining the positions of which correspond to different values.

As can be seen in the graph, 89% of all points have errors in determining the position of points up to 50 mm and 11% – from 50 mm to 75 mm. Most of the points with errors from 50 mm to 75 mm correspond to areas with vegetation; therefore, when cleaning a cloud of points using a filter, their number decreased by three times and corresponds to 3%.

Conclusion

When studying the deformations of the ground surface in the collapse zone from the Ordzhonikidze mine, a digital survey was used, which made it possible, using a 24-megapixel camera with distances of 600-700 meters from the object of study, to obtain the accuracy of determining the spatial coordinates of cloud points from 0 mm to 50 mm. The resulting accuracy is lower than the accuracy of laser scanning, but has advantages when shooting from large distances to the subject. Further research is aimed at improving the methodology for performing survey work and photogrammetric image processing, which will improve the accuracy of determining the spatial coordinates of the studied points and the effectiveness of digital shooting.

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The tragic consequences of the collapse of the earth's surface within the mining allotment of Ordzhonikidze mine

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Abstract. The purpose of this study is to draw the attention of scientists and mining workers to the importance of working off mineral deposits within the permissible parameters of mining and technical production, the failure of which leads to tragic consequences. Based on the analysis of physical data of the rock massif and the geomechanical condition of the exhausted space within the mine field, the causes of disturbances of the stability of the inter-dimensional pillar, its deformation and displacement were determined. The negative and dangerous factors of underground mining are given, which lead to the formation of large cavities, which are kept from collapses due to the inter-dimensional pillar and the thickness of the rocks that supported it. An analysis of the field development violations is given regarding the application of inappropriate systems of development, legislation, regulations, and inefficient design decisions that led to the accident that resulted from these violations. The actual consequences of the accident, which resulted in extensive destruction of the earth's surface, human casualties, seizure of cars, communications, buildings, roads, etc., are presented. Recommendations are given to prevent the collapse of the earth's surface, the destruction of buildings, and the death of people.

1 Analysis of research and publications

A great deal of research has been devoted to the study of the causes and consequences of violations of the technology of underground mining of iron ore deposits, which lead to uncontrolled destroy of safety pillars and the collapse of the earth's surface. Some of these studies explain the uncontrolled destruction of safety pillars due to the lack of proper monitoring of the state of the mountain, disturbed by mining operations, the definition of criteria for forecasting emergencies and the limits of the impact of mining operations on the stability of the earth's surface [1-4]. The authors of these studies believe that monitoring the state of the earth's surface in mining operations will prevent collapses and also avoid distortions of gas and water pipelines.

In the works related to the improvement of the concepts of systematic management of mining processes, it is emphasized that further studies should be directed to the development and improvement of existing technologies of underground mining of iron ores by systems of development with the bookmark of the produced space, which will avoid uncontrolled collapses [5-7].

From the side of the researchers, who pay attention to the necessity of developing a state program of a complex solution of the problems of the Kryvyi Rih iron ore basin (sinkhols and landslides, technogenic earthquakes, etc.). It is concluded that this is possible only at the state level with the attraction of considerable funds, specialized institutions, joint activities of mining specialists [8].

Analyzing the economic and environmental aspects of the technogenic region of Kryvbas, the study shows that the practice and accumulated experience of mining enterprises show that the costs of implementing measures to prevent possible emergencies related to the disturbance of the daily surface in the form of cracks, subsidences and sinkhols are significantly lower than losses to eliminate them [9].

2 Setting objectives

Underground mining is associated with the formation of voids, the untimely repayment of which or not laying them can lead to the uncontrolled collapse of safety pillars and the destruction of not only underground structures but also buildings on the surface of the mine. The purpose of this study isto identify the causes of the collapse of the earth's surface of the mine and to develop recommendations for preventing the uncontrolled destroy of barrier safety pillars within the mine field, which is set aside for the development of mineral deposits.

3 Results and discussion

The subsidence of the earth's surface occurred on June 13, 2010, within the mine drainage of mine Ordzhonikidze PJSC "CENTRAL GOK". An array of rocks, where the uncontrolled displacement of the earth's surface occurred, composed of deposits of ferrous

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quartzites 18-20 m thick, has dismemberment with geological disturbances. Under the oxidation zone, which extends to a depth of 280-380 m, magnetite quartzite was extracted by treatment chambers in the southern and northern wings of the mine. As a result of the ore extraction, waste spaces were formed in both wings from 120 to 200 m. These waste spaces were entirely separated, partially filled with rock, which supported the pillar at its bottom. The array of undermined rocks rested on the rear, which was the mainstay of the north and south wings of the minefield.

The geomechanical condition of the undermined rock massif was such that equilibrium could be formed, since it became a lever whose place of pinching was the unbroken indigenous rocks, and the point of displacement was a pillar. This load concentrated the load from the undermined array of both wings, as from a lever. Besides, the undermined array could be displaced by layering, since within the minefield, it was dismembered by geological shifts, which contributed to its weakening. The weakened fossil mass was further exacerbated by the existing collapse zones created by the mining of rich ores.

The state of the pillar is evidenced by three of his dumping, which occurred in 1988 (two years after its formation), with the thickness of the pillar of the project being 30 m, and in places of dumping remains up to 15 m. Further dimensions are not available due to the difficult approach to measurements, but the state has increased due to the direct mining of ore in the chamber from 2006 and next to it in 2007-2008 with a floor of 527 m.

Thus, the undermined array of rocks of the northern and southern section rested on the pillar, and through the pillarwas transmitted to the ceiling of these chambers and, consequently, to the inter-dimensional pillar floors of 527 m.

The pillar horizon of -170 m was composed of oxidized quartzites, which are 2-3 times less than magnetite ones. It follows that the tense state of the pillar was such that any slight effect on it could lead to its destruction, and as a consequence – the destruction of the support that supported the massif, and this could contribute to the collapse of the worked out mountain range of the northern and southern section.

Slowly, for many years, the increase in the mass of the overlying rock and the plane of its outcrop caused the approaching of the limit state without showing signs of destruction. The massive explosion that took place triggered the displacement of the rock mass, resulting in a cone of influence, with the following parameters: area 165 thousand m^2; collapse on the lying side of the deposit up to 80-82 m; on the hanging side – 5-20 m; void volume – 7.0 million m^3; the volume of waste space along the southern and northern sections is 7.2 million m^3; used space fill factor – 0.97.

The mining circumstances in which the accident occurred are as follows. The raw material base of Ordzhonikidze mine is a deposit of magnetite (ferruginous) quartzites “South-Magnetite”. This deposit is revealed by the main air-shaft of the Ordzhonikidze mine and the ventilation shaft of the mine “Chervona”. Development system – floor-chamber. The testing of inter-chamber pillars (ICP) was carried out by a surface collapse. During the mining of the magnetite quartzite deposit, the mine was guided by the design and technical documentation developed by the State Enterprise “State Institute for Design of mining enterprises “Kryvbasproekt” and the technical department of the Ordzhonikidze mine. Together with the design documents, which were studied by the State Commission for the Investigation of the Accident, scientific reports of the Scientific-research mining institute of the Kryvyi Rih National University (NIGRI KNU) on the carrying out of research work in the period from 2000 to 2009 were presented.

According to the expert commission, appointed by the decision of the special commission to investigate this accident, the design documentation was sufficient for the safe development of the field and the control of the rocks. However, during the mining process, deviations from the project timetable for stock extraction were allowed. So, ICP in the surveyor axes (-4) and (-11) was refined later by 8-12 years, and ICP (-3) axes were not refined. There were also deviations from the “The project of preparation and development of the deposit “South-Magnetite” in axes (-45) - (+40) floors 447-327 m”, 1987 and from the “Project No. 37 on preparation and testing of magnetite quartzites in block (-7) and ICP (-11) and (-3) axis of floor 447-304 m”, 1987.

In order to produce magnetite quartzites, a mass explosion was carried out at the Ordzhonikidze mine on June 13, 2010. The total mass of the explosive used was 65042.5 kg. The mass explosion was carried out by blasting deep wells, as well as by lifting workstations, which housed concentrated vertical charges. The mass explosion was monitored by NIGRI KNU staff, according to a scientific agreement on the topic “Monitoring of values of seismic oscillations of the soil and shock-air waves on the condition of the construction structures of buildings and structures located in the area of blasting on the quarries and mine Ordzhonikidze”.

On the day of the mass explosion, four employees of the blast management laboratory and the seismic mine were delivered to the Ordzhonikidze mine by GAZ 22-17 car (“Sobol”), driven by driver V. S. Vavruk. The seismic equipment locations were determined in advance outside the minefield. After placing the observation posts, the driver V. S. Vavruk, without entering the territory of the industrial site, put the car near the construction of the mechanical workshops of the mine, in which he intended to wait for the completion of the surveillance work.

Immediately after, the explosion began an intense collapse of the daily surface, which was in the mine drainage area. At the distance of 20 m from the checkpoint No. 9 (CP-9) in the southwest direction there was a subsidence of the earth’s surface, together with an array of pressure rocks over a clearing space of about 360 m in length, and in the perpendicular direction – 450 m, with a plane approximately 16 hectares. The subsidence of the earth’s surface (displacement) on the side of the lying side of the reservoir was a maximum of

82 m and 20 m minimum, and on the side of the hanging side of the formation bed, it varied from 5 to 20 m.

Due to the subsidence of the earth's surface, a part of the highway 20 m from the CP-9 went into the abyss together with three private cars and GAZ 33-023 "Gazel" cars owned by PJSC "CENTRAL GOK" and GAZ 22-17 "Sobol" owned by NIGRI KNU, which stood before the CP-9. Driver V. S. Vavruk, who was at the time of the incident in the cockpit of the car "Sobol", received injuries that are not compatible with life.

As a result of subsidence of the earth's surface, the following destruction occurred in the mine drainage zone of Ordzhonikidze mine (Kryvyi Rih):
- damaged the 6 kV transmission line, which was one of the inputs of electricity supply to the mine;
- damaged gas pipeline, which provided gas to residents of settlements located outside the mine drainage area of Ordzhonikidze mine;
- destroyed construction of mechanical workshops of the mine;
- destroyed mine headgear of the ventilation shaft "Chervona";
- destroyed the ventilation shaft "Chervona" intended for ventilation of the mine workings of the Ordzhonikidze mine;
- the substation "Chervona" from which part of the residential sector was fed;
- requested the Brotherly Tomb of the soldiers killed during the liberation of Kryvyi Rih;
- destroyed the public highway leading from CP-9 along Brotherly Tomb to residential areas;
- destroyed the former construction of a repair shop;
- cracks of the earth's surface and the asphalt part of the site were formed on the territory of the Ordzhonikidze mine;
- three private cars, a car for cargo and passenger transportation, GAZ 33-023 "Gazelle" owned by PJSC "CENTRAL GOK" and a car GAZ 22-17 "Sobol" belonging to NIGRI KNU failed.

The State Commission of Inquiry into the accident at the Ordzhonikidze mine established technical and organizational causes and recommended such basic measures to eliminate the causes of the uncontrolled collapse of the earth's surface when developing the deposit "South-Magnetite".

Technical causes:
- unreasonable choice of systems and technologies for the development of oxidized magnetite quartzites, which by physical and mechanical properties are capable of forming the process of self-destruction;
- failure to comply with paragraph 1.2.2. Regulation on designing of mining enterprises of Ukraine and determination of mineral resources of 07.05.2004 No. 221.

Organizational causes:
- not an effective designer's service by NIGRI KNU, as it was only observational. At the same time, reports were issued that did not provide specific suggestions for creating preconditions for self-deception and did not provide an analysis of the effectiveness of the technology used;
- retreats from the "Working project of mining works and collapse of overlying rocks during mining of magnetite quartzite deposits above the horizon of 447 m of the Ordzhonikidze mine". Violation of the schedule of completion of the field, which did not contribute to the normal development of the process of self-destruction;
- the necessary measures were not taken, and the driver has not indicated a safe parking place at the time of the mass explosion.

Measures to protect the surfaces of mines from collapse should include:
- safety of people in buildings and sites located in the designated area;
- the preservation of objects for the purpose of their operation for the whole period of existence of the mine;
- preventing the ingress of water and flooding of mines when undermined water objects;
- prevention of excess losses of minerals or their conservation;
- prevention of unjustified premature demolition or transfer of structures;
- the possibility of applying, where necessary, joint development of deposits in open and underground ways.

The main measures for the protection of objects from destruction during the underground development should be considered as follows:

1. Mining measures that reduce the deformation of rocks and the earth's surface: application of special systems of development, laying of the produced space, incomplete excavation of minerals, the introduction of the special order, and sequence of working out of reserves under-protected objects, etc.

2. Structural measures that allow to maintain permanently or extend the life of structures at deformations of the base exceeding the limit values: separation of buildings into sections using deformation seams, reinforcement of load-bearing structures employing steel rods, stretch marks and reinforced concrete belts, installation of various types and components artificial reinforcement of the foundation of the structure by creating retaining walls, cutting slits, etc.

3. Carrying out of repair and restoration works: repair of a roll and lifting of the densest parts of buildings and constructions through jacking, filling and straightening of joints of rails repair of a roll of support of transmission lines, bypass of power lines, regulation of crane ways and other work to bring the facility to a state that meets the requirements of maintenance.

4. Temporarily change the nature of the operation of the underworked object.

5. Moving structures on not underworked areas.

6. Special monitoring of the development of the displacement and the condition of the underworked objects in order to detect dangerous deformations promptly and take appropriate security measures.

7. Provision of a safety pillar for an object if other protection measures do not ensure its normal operation or are economically impractical.

The protection measures for existing sites are determined by a mining company that develops mineral resources or, on its request, by a special organization and approved in due course. Safeguards for the projected

construction site, as well as the projected deep horizons, are selected by the design organization. When approaching the area of impact of the underground development to the protected object, the planned measures should be revised and corrected in order to prevent the occurrence of emergencies. Any construction of sites in mining impact areas must be agreed with the governmental organization responsible for the proper and safe use of minerals.

Before the drafting of the project of protection of objects located in the areas of influence of underground mining, it is envisaged that they are thoroughly inspected by a commission organized by the mining enterprise. The commission should include representatives of the company, owners of the objects to be guarded, and representatives of the organization that should design the security measures. The survey results are drawn up with an act detailing the technical condition of the object.

In the case of large-scale blasting operations, such as a mass explosion, the commission shall repeat the inspection of the blast zone and amend the security measures to determine the necessary costs of restoring the safe condition of buildings, structures, pipelines, and electrical networks and equipment. Draft measures for the protection of objects located in the area of influence of underground mining works are approved and approved following the procedure established by law and by the rules for mining operations [12]. State mining authorities control responsibility for the timely and correct selection of security measures and their implementation. Business protests against disagreement for damage, such as the destruction of structures and communications, are resolved under the law through the courts. According to the court, the mining company, which was responsible for the rockslide or collapse of the surface and the destruction of structures and engineering communications, must at its own expense, restore communications, repair, or restore the destroyed objects.

After revealing by the state commission, the nature of the process of rock displacement, the destruction of the surface, its contours, and the depths of the dips are applied to surveying cuts and plans. The scheme of the zone of deformation of the rock massif and the earth's surface is shown in Fig. 1, where shear zones, cracks, terraces, funnels, and dips are traced. This scheme was proposed in 1975 by the Institute of Mining Mechanics and Surveying (IMMS).

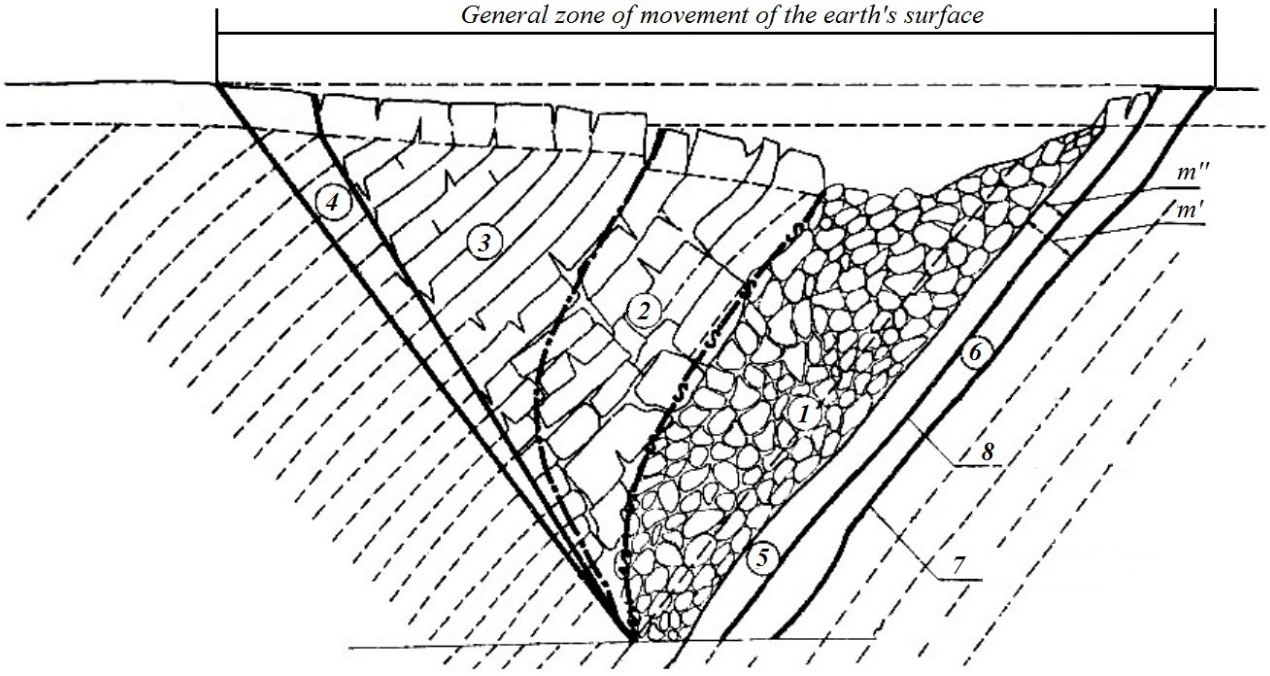

Fig. 1. The scheme of zones of deformation of the rock massif in the hanging and lying sides of the deposit according to IMMS: 1 – cone of influence; 2 – subduction zone; 3 – fissures zone; 4, 6 – smooth shift zone; 5 – fissures zone and subduction zone; 7 – displacement line; 8 – line of shear; *m′* – thickness of layer smooth shift zone; *m″* – thickness of layer fissures zone and subduction.

According to the conclusion IMMS, the zone of landslide displacement is the area that is affected by underground mining if the deformations of the rock mass exceed the permissible values. In this case, in the hanging side of the deposit, shear zones are formed, which are characterized by certain physical and mechanical features:

1. The zone of cracks in which deformations are accompanied by the bending of hinged rock slabs with the formation of cracks, the loosening ratio is less than 1.1. Coming to the surface under sediment, this zone causes them to bend and stretch to form a zone of cracks on the surface of the earth.

2. The area of smooth bending is characterized by the fact that the layers of rocks bend with the formation of unconnected small cracks, the loosening ratio in this zone is close to 1.0. Depending on the deposits, this zone causes the transverse deformation of the layers and slope without breaking the continuity with the formation of a zone of smooth shifts of the earth's surface.

3. The shifting zone of rocks along with the layer in the lying side of the deposit, in which the contact thickness of the rocks is stratified into individual packs, is displaced by the layer. Depending on the deposits, this zone causes them to shift with the formation of cracks and terraces on the earth's surface.

4. The zone of a smooth shift of rocks by layer, in which packs stratify the array, is shifted parallel to the contacts of rocks. Based on the deposits, this zone causes them to stretch and tilt without breaking the continuity with the formation of a zone of smooth shifts of the earth's surface.

Of all the forms of displacement of rocks on the earth's surface, the greatest danger is the cone of the collapse, which is formed suddenly. The sudden collapse of the earth's surface indicates the uncontrolled destruction of the safety pillars of underground chambers, which almost always leads to major accidents in mining. Timely filing of the produced space of blind deposits (deposits that do not reach the daily surface) with an mine rock (rock that does not contain iron of the required concentration) through mining workings or specially drilled wells prevents the formation of a collapse zone over the produced space and eliminates the formation the cone of the collapse.

The filling of the produced space of deposits by the bypass of the collapsed rocks and the filling of the collapsing funnels influences the process of shift and prevents the increase of the collapse zone and thereby prevents the occurrence of other cones of collapse.

According to the influence on the process of displacement of rocks and the earth's surface, the development systems in the Kryvyi Rih Basin are divided into three groups: collapsed, chamber, with the goaf stowing. When using ore collapsing systems and host rocks, the displacement parameters are determined by other influencing factors. Chamber development systems delay the displacement process but do not guarantee the appearance of dangerous landslides and deformations of the earth's surface if the system parameters do not ensure the stability of the host rocks.

The use of development systems with the goaf stowing by filled materials makes it impossible to form a zone of the collapse of rocks, funnels, dips, large cracks on the earth's surface. The parameters of the displacement process, in most cases, depending on the size of the placed deposit, the angle of its fall, the completeness of filling the space produced and the quality of the laying mixture. As evidenced by the practice of using systems with a goaf stowing by hardening materials at the mine "Ekspluataciyna" (PJSC "ZAPORIZKYI IRON-ORE PLANT"), the disturbance of the earth's surface within the mine field is not observed.

The peculiarity of the systems of development with the goaf stowing is the filling of its stowing material gradually with the advancement of the cleaning recess. This system used to prevent the displacement of the earth's surface after the ore blocks have been extracted and sometimes to create favorable conditions for working out the safety pillars. The relatively poor performance of these systems has caused their system to be replaced by collapsing host rocks. However, as mining goes down to great depths and the danger of displacement of the earth's surface increases, the value of stowing systems begins to increase, because at high mountain pressure the laying is the most effective and sometimes even the only possible means of maintaining the mountain range.

The following conditions of use are most characteristic of systems with the goaf stowing:

1. Low capacity of ore deposit – from several centimeters to 6 m. This explained by the fact that the required amount of laying material can be obtained by carrying out main and development workings for laying the produced space of small width.

2. Large angle of the ore deposit. A gentle fall complicates the placement of the stowing material in the working excavation.

3. Resistant ores that allow for a particular time to maintain the waste space unbound.

4. Unstable mine rocks. Because tough ores with stable host rocks can work out with more productive development systems.

5. A high value of ore due to the considerable cost of its extraction.

Depending on the shape and constancy of the elements of the ore deposit, the conditions of application of different variants of systems with the goaf stowing are different. The following main groups can be distinguished:

- systems of development the horizontal slicing with the goaf stowing;
- systems of development the inclined slicing with the goaf stowing;
- overhand store systems of development with the goaf stowing;
- longwall systems of development with the goaf stowing;
- systems of development the strips the goaf stowing.

The sources of obtaining the stowing material have a significant influence on the structural elements of the system, the order, and the technology of the actual mining. There are systems for delivering stowing material from outer space and systems for receiving it within the developing block.

The basic requirements for the stowing material are as follows: the material should be cheap and easily transportable, not have a large shrinkage, be inert in the fire relation, not caking, and also when working the inter-chamber pillars, the material should be compacted and gain stability – to this end, cementing agents added to the stowing material.

Sand, crushed rocks obtained in the mine or quarry, from surface heaps, tailings of preparation plant, boiler, and metallurgical slag, etc. are used as the stowing material.

In most cases, the choice of stowing material determined by the way it transported and placed in the working excavation. On these grounds, the laying divided into dry-gravity, pneumatic, and hydraulic.

Dry crushed material, sand, tailings of processing plants, granulated slag, clay in the amount of no more than 15-20 % recommended for the gravity stowing.

For pneumatic laying, use crushed rocks of such granulometric composition: pieces of size 15-20 mm – 75-80 %; pieces of 0.5-15 mm size – 20-25 %. Clay content should not exceed 10-15 %.

For hydraulic laying, coarse-grained sands and desilted tailings of processing plants used. Great features are the stowing blend, which contains 60% quartz sand and 40% shale gravel with a particle size of not more than 20 mm. The total shrinkage of such material does not exceed 6-9%.

Depending on the material of the laying, the ratio of solid material and water accepted: for sand from 1:0.75 to 1:1; for more extensive material from 1:1.5 to 1:2.5. At Canada's mines, thick paste in the form of paste containing sand or desilted tailings of processing plants has become widespread. The presence of binders (clay, cement, etc.) in the stowing material gives it stability, and it allows even holding in the massif of laying workings without fastening. Such a hardened blend laying, called a "hardening laying", is gaining increasing use in mine shafts.

Given the risk of landslides and collapse of the earth's surface, structures and natural objects are protected concerning their importance, structural features, resistance to deformation, nature of the operation, condition, service life, etc. To increase the effectiveness of security measures, all objects are divided into separate categories, which are shown in the table 1.

To protect residential, public, and industrial buildings that fall into areas of dips, terraces, and cracks, mountainous measures are applied, or warning and security targets remain.

In the area of smooth landslides of the lying side of the deposit, it is allowed to preserve structures and buildings by applying constructive protection measures, which are selected according to the recommendations for designing measures to protect structures and buildings from the influence of mining.

Roads (motorways and access roads), tram lines, motorways, 110 kV transmission lines and below, lines and cables, ground pipelines, etc., which allow eliminating the accumulated deformations are allowed to remain in areas of smooth landslides and cracks, but in projects must justify the repair, restoration, and monitoring of the surface in these areas.

All security measures must be approved by the organizations that operate the facilities.The main recommendations of the State Commission for Investigation of the Consequences of the accident, which occurred on June 13, 2010, at the Ordzhonikidze mine, are as follows:

1. Given the complexity of the mountain-geological conditions of the deposit "South-Magnetite", to clarify its physical and mechanical properties.

2. Develop a standard passport of the development system, taking into account the physical and mechanical properties of the deposit "South-Magnetite".

3. To revise the project "Measures for the protection of buildings, structures, and natural objects from the harmful effects of underground mining".

4. To carry out constant control on the part of the general designer on the observance of design decisions and schedules of working out of mineral reserves.

5. Undertakings carrying out underground workings shall introduce variants of development systems with a bookmark of the produced space from the beginning of operation of the field.

6. Perform scientific research to determine the effectiveness of methods of monitoring the state of the mountain during the development of deposits.

Table 1. Categories of objects located in hazardous areas shift of mining companies.

Protection category	Protected objects
I	1. Structures of the lifting complex of mines: trunks, nettles, buildings, and chambers of lifting machines. 2. Central compressor station. 3. Railways, railway stations. 4. 3-floors and more residential buildings. 5. Public buildings (schools, theaters, clubs, hospitals, etc.) 3 floors and more. 6. Industrial workshops with crane equipment with a capacity of more than 15 tons. 7. Supports of high-voltage power lines with runs between them of 300 m or more. 8. Railway bridges with runs over 20 m. 9. Water mains and pumping stations.
II	1. Ventilation and auxiliary shafts of mines, buildings of the lifting complex and fans. 2. Main lifting shunts, drifts, main lifting chambers, warehouses of explosive materials, electric locomotives. 3. District electric and compressor stations. 4. Mines railway depot. 5. Mining electromechanical workshops. 6. Mine processing factories. 7. Administrative and household plants and residential two and 3-floor buildings. 8. Public double floor' buildings (schools, hospitals, clubs). 9. Water towers more than 20 m high. 10. Boiler rooms. 11. Industrial workshops with crane equipment with a capacity of up to 15 tons. 12. Concrete loading bins.
III	1. Preparatory and threaded workings. 2. One-floor residential buildings, industrial and office buildings. 3. Access mines railway tracks. 4. Local transmission lines. 5. Telegraph and telephone lines. 6. Highways. 7. Collective gardens and parks. 8. Cemeteries. 9. Overpasses of open warehouses. 10. Mines mechanical workshops. 11. Natural and artificial reservoirs. 12. River beds. 13. Water towers up to 20 m high. 14. Ground pipelines.

Conclusion

1. During the development of the deposit "South-Magnetite", there was no proper control over the condition of the produced space by the scientific and design organizations, as well as by the management of the Ordzhonikidze mine.
2. The project for carrying out the mass explosion on June 13, 2010, at the Ordzhonikidze mine was not mentioned in the list of documents analyzed by the state commission. This project should develop all measures for the security of a mass explosion, including the designated locations of security posts and the location of private and business vehicles.
3. Lack of security posts at the approaches to the area of the mass explosion could lead to more terrible consequences of this accident (getting into the area of an explosion of outsiders from surrounding villages, cars, other transport).
4. The main responsible person for the consequences of the accident is the owner of the enterprise, which is stipulated by the Law of Ukraine "On Occupational Safety", the Mining Law of Ukraine, the Rules of Safety during the development of deposits in an underground way [10, 11, 12], whose name is not included in the state commission report which indicates the imperfection of its conclusions.

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Sustainable development of mining processes based on mechanochemical leaching of ore

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Abstract. Intensive development of the mining and metallurgical complex results in considerable volumes of waste materials, more than half of which are produced by mining enterprises. Modern mining and processing can provide non-waste production only if mineral extraction and grade recovery from natural and technogenic mineral materials are regarded as a single technological process and the Earth surface preservation becomes a priority in determining parameters of process integration. The research is aimed at improving of the technology of metal leaching in a disintegrator through complex application of metallic ore concentration tailings. A radical step of reducing mining waste hazards is their utilization through introducing technogenic reserves of metallic ore concentration tailings into production, thus creating a new raw material base for the mining industry. Substantiation of the concept of non-waste utilization of off-grade mineral materials depends on the amount of integration of chemical leaching and mechanochemical activation in the disintegrator and is achieved by means of modern information technologies.

1 Introduction

Mineral extraction is characterized by increasing volumes and areas of mining operations aimed to satisfy humanity's growing needs [1-5]. It results in accumulation of aggressive wastes at all process stages accompanied by intensive impact on the environment causing costly preventive measures (Fig. 1).

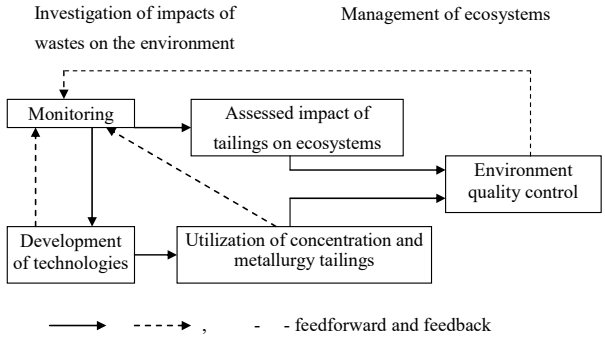

Fig. 1. Control chart of environmental conditions with regard of waste utilization

Tailings of mineral treatment are almost not applicable and hazardous to store, yet their rational use can provide great economic efficiency [6-8].

Man-made deposits result from changed requirements to marketable ores, selective extraction of rich deposit sites and increased volumes of pillars under complicated conditions of filling voids with consolidating mixtures [9-10].

The volume of reprocessed mineral wastes does not exceed a few percent of the total mineral output. It is explained by the fact that technologies applied do not enable extracting useful components from waste materials. Currently, each technology of ore mining and processing is characterized by some economically reasonable limits of extraction conditioned by mining parameters [11-13].

This approach complicates sustainable use of natural resources and cannot be changed at present. Methods of control intended to improve resource use and decrease man-made wastes can solve the mentioned problems [14-17].

Intensive development of mining and metallurgical complexes results in accumulation of considerable amount of wastes, more than half of which is produced by the mining industry [12, 18-20]. Many scientific works deal with technological solutions of waste utilization problems [21-24].

At the same time, the degree of efficiency of utilized wastes is extremely low [25-26]. Only 15% of large ore deposits consider mining and treatment wastes as part of their technological cycle. Industrial wastes are mostly used as construction materials and to manufacture consolidating mixtures.

According to modern ideas, wastes can include natural, man-made and natural-technogenic resources (pillars). Man-made deposits are formed without considering their subsequent reuse. Although, there are some man-made deposits designed to ensure certain technological, geomechanical and physical-mechanical

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parameters necessary for their future re-treatment.

Mining and processing enterprises can be waste-free only if issues of extracting minerals from the Earth's interior and valuable components from natural and man-made mineral materials are considered as a single technological complex and the Earth surface preservation becomes a priority in determining parameters of process integration.

In mining, complex waste utilization provides for deep re-treatment of man-made materials accompanied by extracting gold, platinum, palladium, silver, non-magnetic hematite and other useful components as well as removing heavy metals and radionuclides to meet sanitary requirements (Fig. 1).

In developed industrial countries, utilization of industrial wastes reaches 70%. In the USA, for example, 20% of aluminum, 33% of iron, 50% of lead and zinc and 44% of copper are produced as a result of re-processing mine wastes. In the state of Montana (USA), 2 t of gold and 4 t of silver are obtained annually at waste dumps with 0.84 g/t of gold and 2.8 g/t of silver content. In Michigan (USA), 60% of copper is extracted from mill tailings with 0.3% copper content [1-3, 20-24].

Every year, in the RSA, 3.5 t of gold and 700 t of uranium are produced at waste dumps of gold mining mills with 0.53 g/t gold and 40 g/t uranium content, average productivity making 50 000 t/day. The same trend is observed in Canada, Great Britain, Spain and other countries [11, 20-24].

When recycling industrial wastes, the cost of marketable products is 10-15 times less than those produced by conventional methods. Therefore, development of this trend can result in profits comparable with basic production [27-30]. For instance, recycling 150 million ton of concentration wastes of manganese ores of Nikopol region and 500 million t of concentration wastes of Kryvyi Rih iron ores can result in manufacturing products that worth 5-7 billion USD. To update tailings recycling, there are used methods of magnetic, gravity and electrochemical separation and concentration of off-grade materials. They allow extracting such basic waste components as iron, manganese, titanium, sulphur and silica by applying magnetic separation and sorting them into selective marketable products, thus making separation and concentration of the rest waste materials by gravity methods highly effective [12-15].

Electromagnetic separation, flotation, gravity and other methods are applicable to concentrating industrial wastes and semi-finished products of steel mills [31-34]. For instance, flotation of copper and nickel is used at many national and foreign enterprises; pneumatic treatment of clinker – at some national enterprises; flotation of acid agglomerated cake resulting from cinder leaching – at zinc producing mills of Risdon (Australia), Kosaka (Japan) and Trail (Canada); retort residue jigging – at the mill of Fridrich-August (Germany).

Conventional concentration technologies have some extraction limits resulting in tailings that become unfit for further use.

Mining conditions tend to deteriorate nowadays. Prospects of the mining industry and environmental safety should be assessed considering the fact that demands for mining products are difficult to satisfy in spite of new deposits being developed.

Mineral treatment implies that from 30-40% to 99.9% of mined rock mass will turn into tailings. While expansion of tailings ponds result in destroyed vegetation and soils, increased height of tailings causes favorable conditions for dust dissemination and contamination of the biosphere of nearby areas. 20% of claim areas are occupied by rock piles, 13% – by tailings ponds of concentration plants, 5% – by dumps and wastes and 3% are turned into unfit for further use because of disturbed surface. About 0.1 ha of farming lands per 1 000 t of raw materials is expropriated for waste disposal [1-2, 11].

Almost all mineral deposits are located in areas of seismic activity. Tens and hundreds cubic meters of unfilled voids are created as a result of mining operations. The voids react to geodynamic and seismic changes in the region and can cause similar changes by themselves. Seismic safety of rock mass is a system of controlling the risks caused by seismic oscillations of various intensity in a given period of time.

Modern technologies preserving the lithosphere are based on principles of protecting the Earth's surface from disruption caused by mining operations thanks to controlling geomechanical balance of the rock mass in the course of mineral extraction and any time after it. They provide filling voids with consolidating mixtures and tailings of leaching metals from ores in situ.

The influence of mining on the Earth lithosphere is determined by sizes of mine fields and workings, areas of undermining, extraction volumes and the ratio of broken rock mass to the hoisted one.

Rich ore reserves localized in favorable conditions are not sufficient. Therefore, deeper levels of existing mines and former reserve deposits with complicated mining and geological conditions are going to be developed in the nearest future. It is associated with reduced metal content in mined ores, increased volume of waste materials and augmented load on the environment [12, 16-17].

Currently, mining production is characterized by scarce mineral reserves and escalated nature-man relationship. That is why, in choosing an efficient design, environmental damage and mineral losses in situ should be taken into account.

Accumulated tailings are caused by application of mechanical energy only in the majority of traditional technologies of concentration and metallurgy. Chemical leaching in percolators does not increase metal extraction, yet it takes longer time. Leaching in a disintegrator has recently appeared as a new technology [35].

Problem statement of the research is substantiation and analysis of the suggested technology of metal leaching in the disintegrator, which is aimed at integrated application of tailings of metalliferous ores concentration.

2 Materials and methods

Activation of a substance by great mechanical energy under the processing speed of more than 250 m/sec in the disintegrator results in electrically unbalanced charged centers in the material, thus radically changing mineral

properties. The mechanochemical technology enables production by 30% cheaper, saving 30% of energy.

This trend is unique and opens up potential for revolutionary changes in ore treatment, modern information technologies ensuring its advantages by:

– application of computer-aided methods to control parameters of a process;

– versification of design variants;

– development of calculations and machine-language programs;

– development of simulation design complexes.

Efficiency of the mechanochemical technology can be proven experimentally. The first step of its substantiation is formalization of experiment requirements.

The following variants of extracting metals from mill tailings of various ores are compared: basic agitation leaching; agitation leaching after activation in the disintegrator; leaching in the disintegrator.

While conducting an experiment according to Venken-Box mathematical planning, the following independent factors are determined: sulfuric acid content in the solution (X_1) of 2-6-10 g/l; sodium chloride content in the solution (X_2); ratio of the leaching solution mass and that of tailings (X_3); time of leaching (X_4) within 0.15-0.625-1.0 h.

Tailings of complex ores of Sadon deposit (the Republic of North Ossetia – Alania) contain, %: zinc – 0.95; lead – 0.84; silver – 0.015; copper – 0.18; manganese – 0.015, etc. Reagent leaching in the disintegrator results in almost similar extraction of metals as compared to separate activation in the disintegrator, yet it reduces the process duration by 2 orders of magnitude. In the decreasing order, the process is affected by the reagent content in the leaching solution, disintegrator RPM, the number of treatment cycles, and mass ratio of the leaching solution and tailings.

Regression analysis of the research results provides the following mathematical models:

$$\varepsilon = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_{12} + a_6X_{22} + a_7X_{32} + a_8X_{42} + a_9X_1X_3 + a_{10}X_1X_4 + a_{11}X_2X_3 + a_{12}X_2X_4 + a_{13}X_3X_4, \quad (1)$$

where X_1 is H_2SO_4 content in the leaching solution, g/l; X_2 is NaCl content in the leaching solution, g/l; X_3 is the ratio of solid and liquid phases; X_4 is RPM of the disintegrator, Hz.

The determination factor for the zinc extraction dependency makes R_2=0.85851, for lead extraction dependency R_2=0.78037, for iron extraction dependency R_2=0.94587.

To achieve objective assessment of changes in dependencies, the graphic-analytical method is applied. To present changes of extraction values of larger groups of metals, there are diagrams of dependencies of metal extraction on each predictor, while the values of the three left predictors are averaged, i.e. for X_1=6 g/l, X_2=90 g/l, X_3=7, X_4=125 Hz (Fig. 2-5).

The dependencies are continuous and are characterized by flex and extremum points in the diagram indicating accuracy of mechanochemical activation for leaching metals in the disintegrator. Dependencies between studied parameters of multi-grade materials and indices of metal extraction can be used to find optimal parameters in solving optimum problems by IT methods.

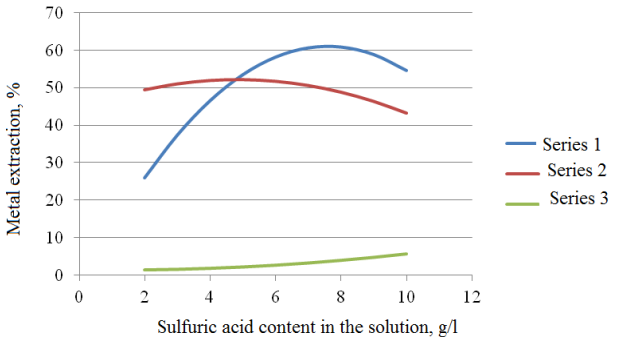

Fig. 2. Dependency of metal extraction in the solution on sulfuric acid content in the leaching solution:
Series 1 is zinc extraction ε = -1.1144 X_{12}+16.942 X_1–3.4359;
Series 2 is lead extraction ε = -0.3352 X_{12}+3.2464 X_1 + 44.31;
Series 3 is iron extraction ε = 0.0529 X_{12} – 0.115 X_1 + 1.4897.

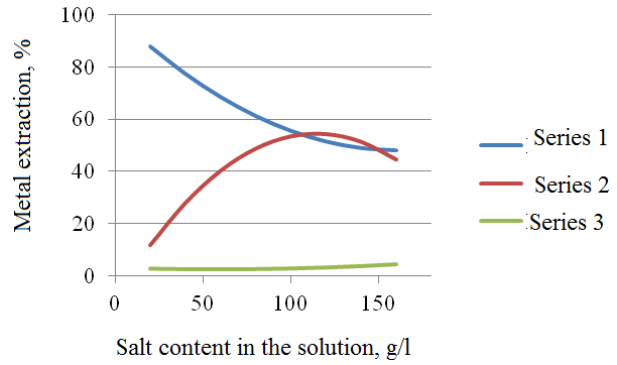

Fig. 3. Dependency of metal extraction in the solution on salt content in the leaching solution: Series 1 is zinc extraction ε = 0.002 X_{22} - 0.6422 X_2 + 99.776; Series 2 is lead extraction ε = -0.0048 X_{22} + 1.0994 X_2 – 8.345; Series 3 is iron extraction ε = 0.0002 X_{22} – 0.0222 X_2 + 3.14.

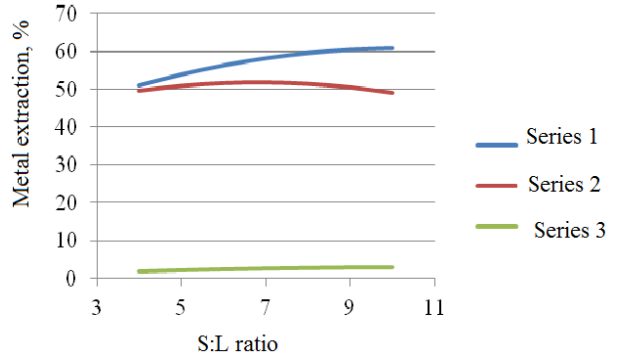

Fig. 4. Dependency of metal extraction on the ratio of solid and liquid phases:
Series 1 is zinc extraction ε = -0.2466 X_{32} + 5.062 X_3 + 34.75;
Series 2 is lead extraction ε = -0.2603 X_{32} + 3.5523 X_3 + 39.61;
Series 3 is iron extraction ε = -0.0282 X_{32} + 0.5917 X_3 - 0.0553.

3 Results and discussion

The developed concept of waste-free treatment of off-grade mineral materials includes the following principles:

1. Conventional concentration does not provide full exposure of minerals and cannot be applied to deep extraction of minerals from mill tailings.

2. There is a promising trend of improving extraction of minerals from off-grade mineral materials by combining chemical leaching and mechanical activation in the disintegrator where the leaching solution is pressed into formed cracks facilitating the extraction rate which is inaccessible for traditional technologies.

3. Parameters of mechanochemical leaching of components from metal-bearing raw materials are subjected to forecasting on the basis of experiments by unified methods of formalizing requirements.

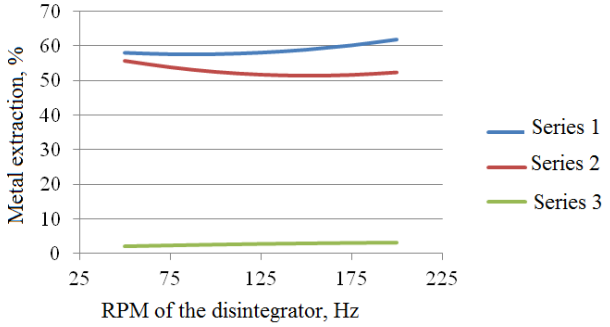

Fig. 5. Dependency of metal extraction on intensity of mechanical activation or RPM of the disintegrator:
Series 1 is zinc extraction $\varepsilon = 0.0003\ X_{42} - 0.0555\ X_4 + 60.038$;
Series 2 is lead extraction $\varepsilon = 0.0004\ X_{42} - 0.1215\ X_4 + 60.658$;
Series 3 is iron extraction $\varepsilon = -0.00002\ X_{42} + 0.0122\ X_4 + 1.5468$.

Environmental and economic efficiency of the modern mining complex should be characterized by minimal material, energy and other expenses to produce marketable products and prioritize preservation of ecosystems and sustainable mineral use. When determining profitability of mineral mining, one should consider mined resources that are not turned into marketable products and become lost.

The model of efficient use of off-grade mineral materials contained in mill tailings looks like [13]:

$$\sum_{t=1}^{t_{bp}+t_{rp}} \Pi_{prt} = \sum_{t=1}^{t_{rp}} A_t\left(Z_{mt}-C_{mt}\right)\frac{1}{\left(1+E\right)^{t_{p}-1}} + \sum_{t=1}^{t'_c} K_x\left(1+E_н\right)^{t'_c} + \\ + \gamma_x\left[\sum_{t=1}^{t_{rp}} A_{pt}\left(Z_{mrt}-C_{mrt}\right) - \sum_{t=1}^{t_{bp}} K_{dat}\left(1+E_c\right)^{t_{bp}}\right], \quad (2)$$

where γ_x is the yield of off-grade materials, unit fraction; A_t is production capacity of an enterprise in the *t*-th year, t/year; t_{rp} is a rated period of application of a technical design, years; t_{pba} is a period of building auxiliary facilities for re-treatment, years; t'_c is a period of construction, years; Z_{mt} and C_{mt} are the extracted value of mined rock mass and expenses for mining and processing in the *t*-th year, UAH/t; K_{xt} construction investments in the *t*-th year, UAH; A_{pt} is production capacity of an enterprise for off-grade materials retreatment in the *t*-th year, UAH/t; Z_{mrt} and C_{mrt} are the value extracted from off-grade materials and re-treatment costs in the *t*-th year, UAH/t; K_{dat} is expenses for constructing and developing auxiliary facilities in the t-th year, UAH; E is the factor of discounting expenses and profits in terms of time, unit fraction; E_c is a bank-credit interest for performing auxiliary operations, unit fraction.

The environmental and economic model of efficiency of off-grade materials re-treatment by the maximum profit criterion and considering the region environment is the following:

$$\Pi = \sum_{p=1}^{P}\sum_{o=1}^{O}\sum_{r=1}^{R}\sum_{t=1}^{T}\sum_{f=1}^{F}\sum_{n=1}^{N}\left\{\left(M_{ey}Z_{my} + Q_yZ_{qy}\right)\right\} - \\ -\sum_{w=1}^{W}\left[K\left(1+E_{ny}\right) + E_q + E_x\right] - \\ -\left[\left(M_eZ_m + QZ_q\right) + Q_gZ_g\right]\times \\ \times K_cK_yK_tK_bK_gK_{vr}K_{ch} \to \max \quad (3)$$

where P is utilization products; Q is types of off-grade materials; R is re-treatment processes of off-grade materials; T is re-treatment time; F is phases of existence of a mine and a plant; N is a stage of off-grade material utilization; W is expenses for off-grade materials utilization; K is capital investments for arranging a utilization site; K_c is a self-organization factor of off-grade material storages.

The mathematical model of leaching metals from ores correlates to conditions and technological features of metal extraction described by regression dependencies and subjected to forecasting.

The complex composition of mill tailings containing the first and the second hazard class substances does not enable their utilization without waste neutralization. Available technologies of re-treatment cannot extract valuable components under their low content to meet required sanitary standards.

Tailings re-treatment can make the need to store utilized tailings on the surface redundant and corresponding lands can be returned into farming use [36].

Metal-bearing tailings can be re-treated only in case of metal extraction according to sanitary standards. Mechanochemical re-treatment is able to meet these requirements. Tailings of mechanochemical activation of mill wastes are a dispersed mass of particles about 0.1 mm in size noted for a more uniform structure, which facilitates re-treatment quality.

In re-treatment of man-made deposits, there are used off-grade reserves, the amount of which is comparable with initial reserves of large deposits. If there are available capacities to utilize off-grade materials, it becomes efficient as expenses for their retreatment are already amortized.

The economic effect of developing man-made deposits includes increased extraction of metals with minimal production expenses and re-treatment stages to obtain a marketable product.

The maximum economic effect of introducing innovative technologies is achieved due to increased mineral reserves, production conversion and extended life-cycles of deposits.

To compare technologies with different mineral extraction rates, it is necessary to assess losses of minerals in comparable units of measurement. When evaluating

losses, it is reasonable to analyze the lost value of components determined by the limit prices of the industry. It enables the single criterion of the technology - profits allowing for damage by mineral losses both in situ and tailings.

Putting wastes of no industrial use into operation has a great impact on the amount of extracted reserves and metal content of the mined ore, thus reducing operational costs and improving efficiency of investments and production assets.

Elimination of the need to store tailings on the Earth's surface can ensure profits by selling re-treatment products, returning lands into economic use and improving the region's environment.

Conclusions

Metal-bearing mine wastes accumulated on the Earth's surface present a global problem that can be solved by their utilization which turns hazardous off-grade materials into a valuable resource.

Human demands in metals can be satisfied by using concentration tailings as a new raw material base of the mining industry, thus solving the problem of deficiency of some metals. Substantiation of the concept of the waste-free re-treatment of off-grade mineral materials depends on combining chemical leaching and mechanochemical activation in the disintegrator treated as a single technological cycle.

Scientific novelty is that for the first time, the method of improving efficiency of the technology of leaching metals from the currently substandard mineral materials through combining chemical leaching and mechanical activation in the disintegrator where the leaching solution is pressed into the cracks resulted from particle destruction has been substantiated, this providing for efficient speed of recovery impossible under the traditional technology.

There are three variants of recovery of metals from ore concentration tailings of various types: basic agitation leaching, agitation leaching after activation in the disintegrator and leaching in the disintegrator.

It is demonstrated that in comparison with separate activation in the disintegrator and leaching outside the disintegrator, reagent leaching in the disintegrator provides almost the same metal recovery, yet it reduces duration of the process by two orders of magnitude. It is determined that the process is affected by the following factors in the descending order: reagent content in the leaching solution, rotor frequency in the disintegrator, the number of processing cycles in the disintegrator and the mass ratio of the leaching solution and tailings.

The regression analysis of the experiment results provides for mathematical dependencies of metal recovery on the content of H_2SO_4 and NaCl in the leaching solution, liquid-solid phase ratio, and rotor frequency of the disintegrator. The determination factor for the zinc recovery dependency makes $R^2 = 0.85851$, that of lead recovery is $R^2 = 0.78037$, and that of iron recovery is $R^2 = 0{,}94587$.

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The study of the stress-strain state of the massif in mining uranium at "VOSTGOK" deposits

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Abstract. Being one of the world's largest uranium producers(about 2% of the world's production), the state enterprise "Vostochnyi Mining and Processing Works" ("VostGOK") provides about 40% of Ukraine's nuclear power stations with uranium raw materials. Considering the conditions of uranium deposits exploitation (location in densely populated areas, protected sites etc.), to protect the environment from possible emissions of radioactive elements room mining is applied with subsequent backfilling of the dead area with consolidating mixtures. This technology is economically reasonable at deposits with the increased uranium content. To exclude a number of labour-consuming and environmentally dangerous operations from the production process, lean uranium-containing ores are reasonable to be mined applying underground block leaching. This enables reaching maximum values of mineral extraction and avoiding considerable material expenditures on backfilling mixture preparation and backfilling dead rooms, as they are almost completely backfilled with the muck pile, and on utilization of waste after the mined ore primary processing (barren rocks and off-balance ores) on the daylight surface.

1 Introduction

Further cut of costs can also be achieved through mining deposits by vertical double blocks. Ore body 10 of the Michurinskoye deposit is supposed to be mined in blocks 10-2 and 10-3 at the 325-184 m level at the Ingulskaya mine (Fig.1).

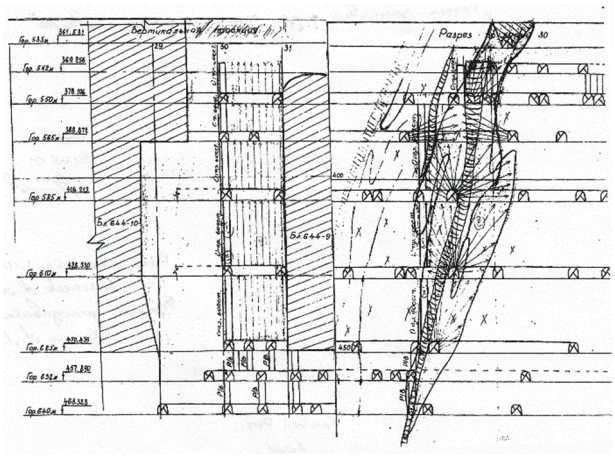

Fig. 1. The vertical plane of blocks 10-2 and 10-3 (ore body 10 of the Michurinskoye deposit).

The process is as follows. Another room is located under the temporary pillar-crown below the dead room backfilled with the muck pile. Under this pillar in the block located further down the dip angle compensatory room is placed to which reserves of this block are broken and the temporary crown is brought down. The solution for leaching uranium ores is fed from the existing workings over the room of the upper block. At this, volumes of mining are cut and pipes are again used for feeding the working solution to blocks [1-3].

The levels of stress in main structural units and in the enclosing rock massif, the condition of the roof bar (the degree of its disturbance caused by workings and deep shafts) are different from those occurring when the traditional technology is applied. Besides, the crown is affected by reagents for underground block leaching. Due to all that, factors impacting the crowns stability and mine safety on the whole require urgent investigations.

Determining permissible dimensions of main structural element of room mining systems [main regulatory documents [1, 2] however, do not consider the influence of the ore bed dip and are not intended for determining the safe thickness of a roof. The technology of underground block leaching of uranium ores in vertical double blocks is a new one to be applied at VostGOK underground mines and requires scientific support [4-7].

To study the stress-strain state and stability of crowns depending on the dip of ore bed and the conditions of the above mentioned blocks, mathematical modelling applying the finite-element technique was applied. The range of boundary conditions of the impacting factors included values characteristic of all the underground mines of "VostGOK". Uranium ore hardness varied from 9-11 to 14-16 on the Protodyakonov scale, that of the enclosing rock - 13-15, the dip of ore body made from 60°

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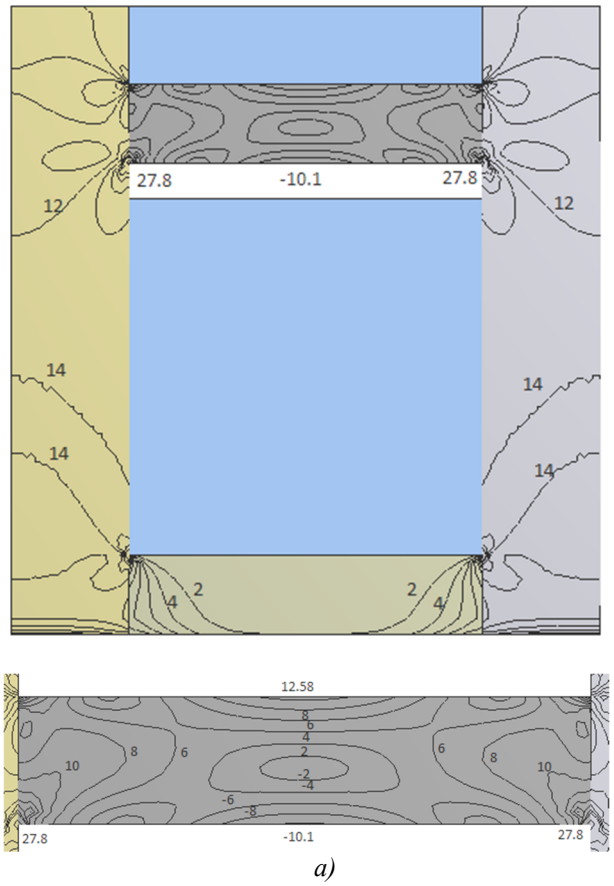
to 90°(in increments of 10°). The stress-strain state was calculated for roofs of 10 to 14 m thick. For calculating the stress field characteristics ANSYS 18 was used [8-10].

The results of modelling the stress-strain state of 10 m thick roofs in ores of various hardness with the ore body dip angles of 90°, 70° and 60° are presented in Fig 2, 3 and 4 [11].

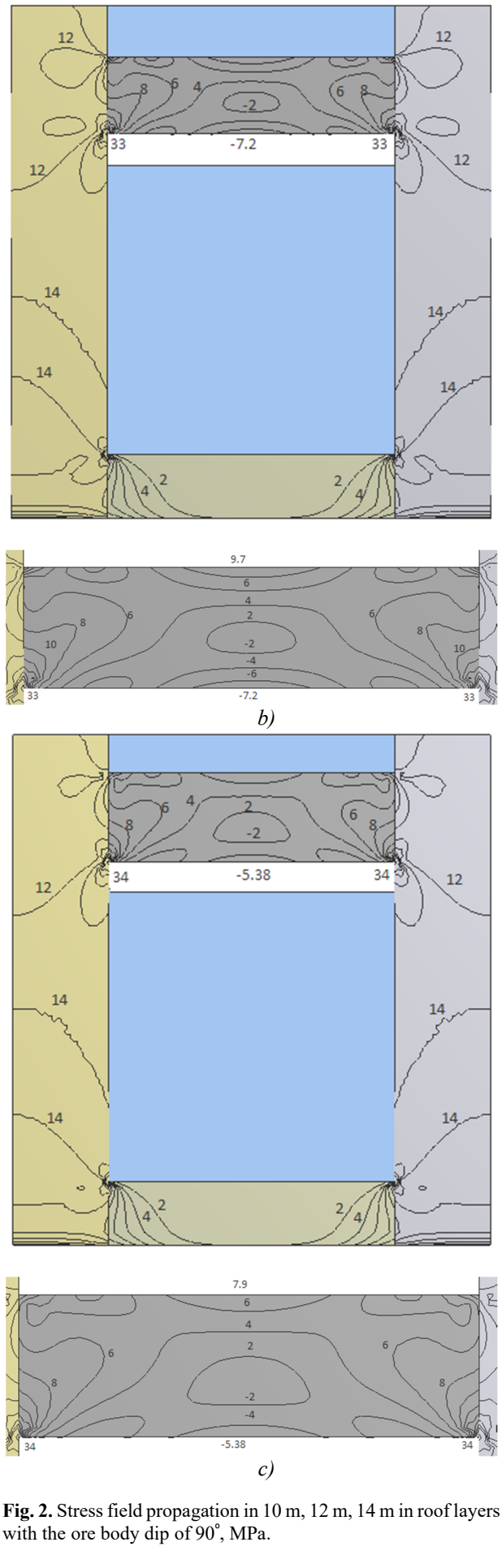
2 Methods

As is seen, the tension stress zone in the lower central part of the crown is the most dangerous. This corresponds to the classical concepts of stress field development in the so called "stress relief arch" that occurs when the massif is undermined by the lower block room. As ore hardness reduces, absolute values of stress in the crown decrease slightly (by 0.1…0.5 MPa, i.e. from 1…2 to 6…7%). This can be explained by the fact that less hard ores are less liable to accumulate stress as they get relieved through deforming towards a post mining voids (i.e. the room) and, on the opposite, harder ores tend to accumulate stress due to smaller deformations. However, stability of less hard ore crowns decreases due to reduction of their ultimate strength [12-14].

For instance, with the ore body dip angle α = 90° and hardness of 14-16, the value of tensile stress in the lower part of the crown reaches 10.1 MPa (Fig. 2, a). However, as ultimate tensile stress of such ores is about 11 MPa, these stresses will not cause failures.



a)



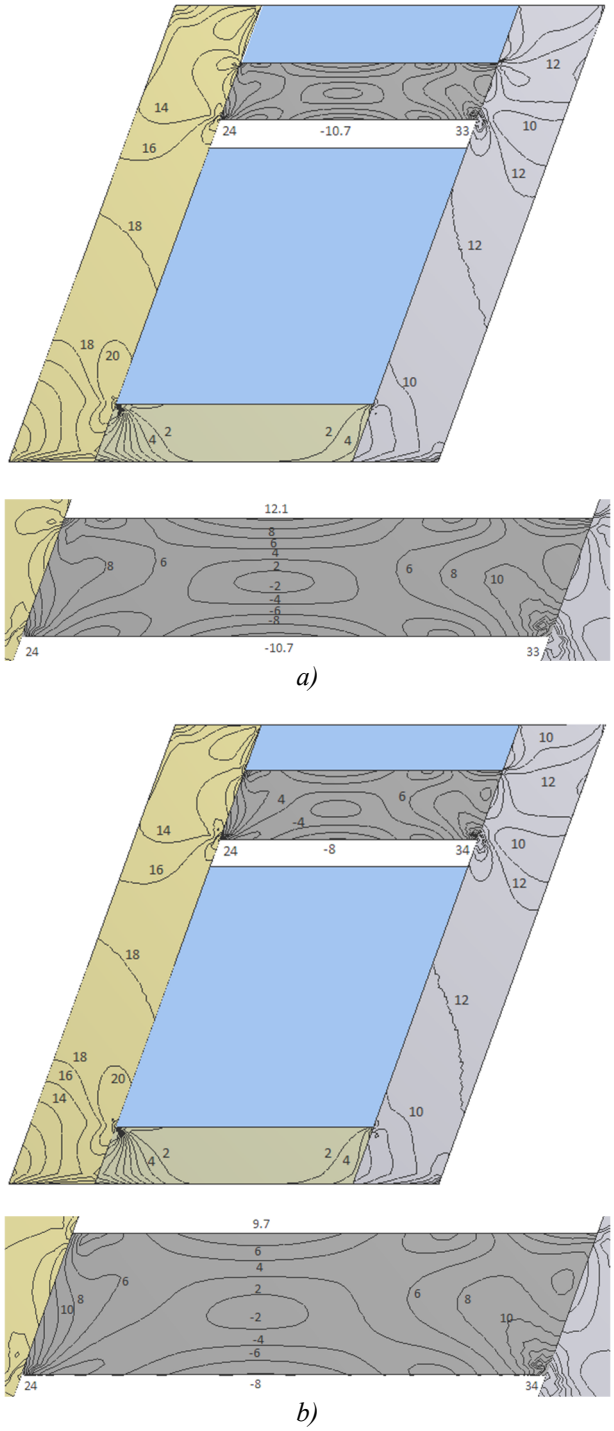
b)

c)

Fig. 2. Stress field propagation in 10 m, 12 m, 14 m in roof layers with the ore body dip of 90°, MPa.

When the crown is made of ores of 10-11 points (Fig. 2,d), the tensile stress level makes 9.9 MPa. With the ultimate strength of the ores of 7.7 MPa this will cause rock falls of about 100…150 m^3 (according to "Instructions…" [15] used at "VostGOK" mines, rock falls of over 250…300 m^3 are considered critical).

With the dip angle α = 70° and ores of 14-16 points roof failures do not practically occur (Fig. 3, a), with α = 60° small rock falls (3-5 m^3) may occur even in crowns of ores of the same hardness (Fig. 4, a). In roofs of ores of 10-11 points with α = 70° (Fig. 3, b) and α = 60° (Fig. 4, b) the volume of rock falls will make from 150 to 200…220 m^3, sometimes to 400…450 m^3 respectively [16-18].



a)

b)

c)

Fig. 3. Stress field development in 10 m, 12 m, 14 m crowns with the ore body dip of 70°, MPa.

These values testify to the critical condition of the crown at angles about α = 70°, at about α = 60° the crown will fail.

Thus, the obtained results testify to the considerable impact of the ore body dip angle on the stress-strain state of crowns and their stability and enable us to suggest application of the correction factor K_α, whose numerical values are given in Fig. 5. [19-22] So, when determining the minimum permissible thickness of the crown in certain conditions, its value obtained without this factor should be corrected through multiplying it by the corresponding value K_α [23-26].

Changes in the existing stress fields, increase of absolute values of current stresses caused by technological workings result in decrease of the crown stability.

Due to this, when determining safe dimensions of exposures and pillars, they should be corrected considering the accepted criteria. In the first case, the crown thickness is determined according to conditions of the room mining order in compliance with the instructions developed by NIGRI (Research Ore Mining Institute) [27]. In the second case, the correction factor is applied.

We suggest correcting thickness of the crown with workings using the expression

$$h_{cr}^{n} = h_{cr} \cdot K_{dist}, \text{ m}; \quad (1)$$

where h_{cr} is thickness of the monolith crown, m; K_{dist} is the factor considering disturbance of the crown resulted from mining, unit fraction [28-31].

As the disturbance degree of the crown depends on the number of workings in it, their geometrical dimensions and thickness of the crown itself, we suggest determining the numerical value of K_{dist} as the product of separate

universal factors [32-35]. Each of these factors differentially takes into account the impact of a particular working on the crown stress-strain state and, consequently, on its stability, as follows

$$K_{dist} = K_1 \cdot K_2 \cdot \ldots \cdot K_n, \text{ unit fraction;} \quad (2)$$

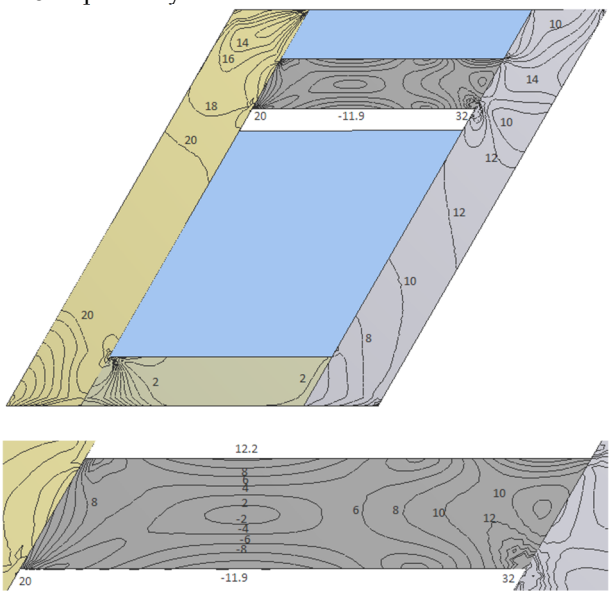
where K_n is the number of workings in the crown.

Numerical values of these factors calculated individually for each working can tentatively be determined as follows

$$K_i = \sqrt{1 + (h_i^w / h_{cr})}, \text{ unit fraction;} \quad (3)$$

where h^w_i is the i-th working height (width), m.

For instance, according to the calculations, the minimum permissible thickness of the crown not disturbed by workings is h_{cr} = 10 m. In case of workings of 2.5, 3.0, 3.5 and 4.0 m, the correction factors for each of them determined by (3) will equal 1.12, 1.14, 1.16 and 1.18 respectively.



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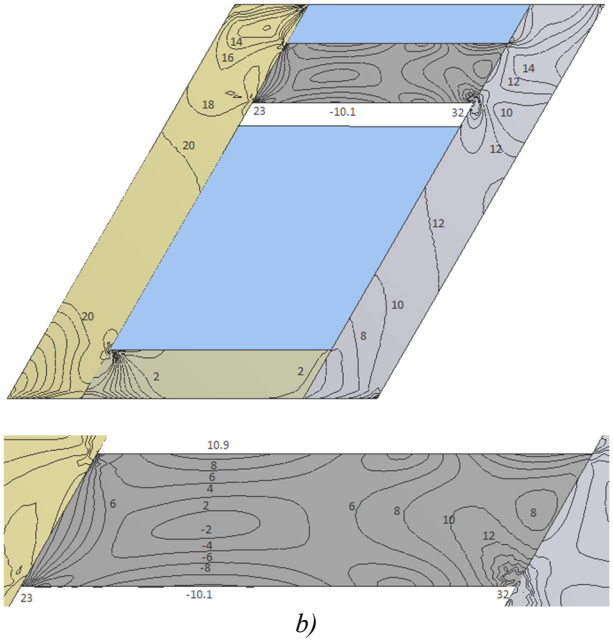

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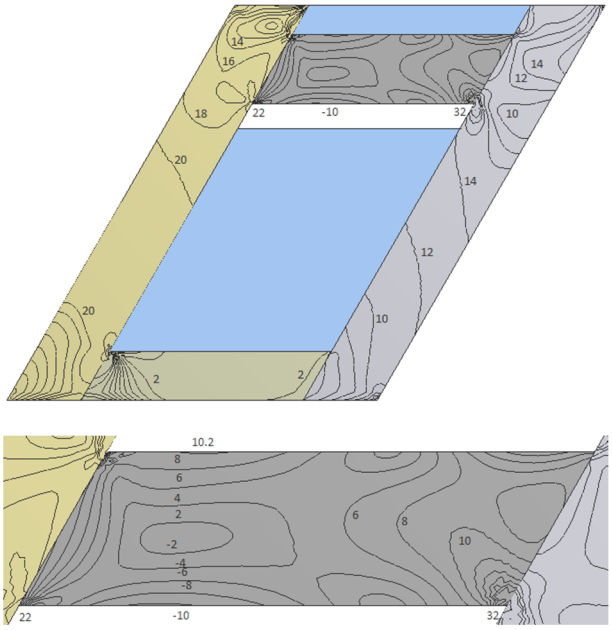

c)

Fig. 4. Stress field development in 10 m, 12 m, 14 m crowns with the ore body dip of 60°, MPa.

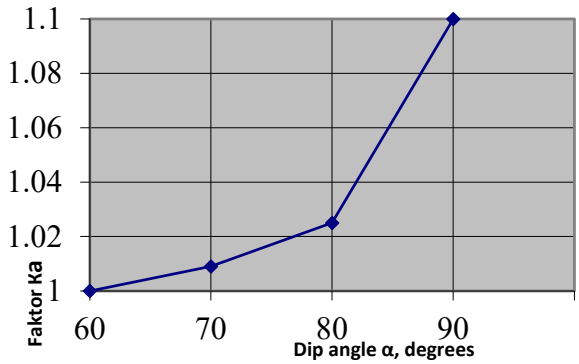

Fig. 5. K_α values depending on the ore body dip angle α.

Thus, the crown thickness should be increased to 11.2, 11.4, 11.6 and 11.8 m respectively [36-39].

If there are 2 workings of 3.0 m and 3.5 m in the crown, the correction factor will make K_{dist} = 1.14·1.16 = 1.32. Correspondingly, the disturbed crown thickness should be increased to 13.2 m [40, 41].

If there are 3 workings of 2.5 m, 3.0 m and 3.5 m in the crown, the correction factor will make K_{dist} = 1.12 · 1.14 · 1.16 = 1.48. Under such conditions the crown thickness should be half as much as that of the monolith crown and make 14.8 m.

3 Results and discussion

So, the crown thickness should be corrected considering decrease of its stability caused by workings. This will help avoid its complete or partial failure.

As shrinkage stoping with sulphuric acid treatment is one of the main components of underground block leaching of uranium ores, the crown separating the rooms will also be exposed to the sulphuric acid.

The research conducted enables the authors to assume that the longstanding (from 3-4 to 6 months) exposure to the sulphuric acid may negatively impact strength properties of the ore massif of the crown. This assumption is substantiated by data on the physical and mechanical properties of rocks of the Michurinskoye deposit, particularly albitites and migmatites which are the most representative rocks in uranium ore occurrence zones. Thus, the average compressive resistance of rocks in their natural humidity conditions and when water-saturated makes 164.4 MPa and 127.5 MPa for albitites and 153.1 and 112.4 MPa for migmatites respectively. That is, if compared with the natural state, water saturation of rocks reduces their compressive resistance by 22…27%.

The analysis of the data on the physical and mechanical properties of rocks of the Michurinskoye deposit, particularly albitites and migmatites which are the most representative rocks in uranium ore occurrence zones, enables the authors to conclude that the longstanding (from 3-4 to 6 months) exposure to the sulphuric acid may negatively impact strength properties of the ore massif of the crown. The average compressive resistance of rocks in their natural humidity conditions and when water-saturated makes 164.4 MPa and 127.5 MPa for albitites and 153.1 and 112.4 MPa for migmatites respectively. That is, if compared with the natural state, water saturation of rocks reduces their compressive resistance by 22…27%.

The impact of the sulphuric acid solution on the crown stability was confirmed by the following investigation. Forty ore cubes with 50 mm sides were divided into two groups. The first group of 10 cube shaped samples was used to determine the uniaxial compressive resistance in the natural conditions, the remaining cubes were used for determining the degree of the sulphuric acid solution impact on the samples' strength.

To provide conditions of the crown contacting the acid solution, in the laboratory environment only one face of an ore sample contacted the acid solution. The other faces of the cubes were covered with two coatings of paraffin. These cubes were placed in a vessel with the sulphuric acid solution which is used for spraying the shrinked muck pile in underground mines of "VostGOK". Tests of uniaxial compressive resistance were carried out 2.5, 4 and 6 months after dipping to determine the impact of the exposing time on the uranium ore strength. These periods correspond to the minimum and maximum time of the reagent impact in real conditions.

The laboratory hydraulic press is able to produce pressure up to 50 t. In relation to the cubes' surface $S = 25$ cm^2 the corresponding pressure makes about 2000 kg/cm^2, or 200 MPa. The press is coupled with a computer that sets the loading rate for the samples and forms the loading diagram for each of the samples with the automatic recording of the current load, maximum pressure at the moment of their destruction and calculates ultimate strength of each sample depending on its sizes. During the tests the minimum loading rate of 1 kN/s was set according to corresponding standards (from 1 to 5 kN/s).

The samples of the first group demonstrated the average value of the uniaxial compressive resistance of about 130 MPa. According to the instructions [42] this value corresponds to the rock hardness ratio of 11 points. For the samples exposed to the sulphuric acid solution during 2.5, 4 and 6 months, average strength values made 82…84.5, 79.5…80.5 and about 78 MPa respectively, i.e. their ultimate strength decrease (in relation to the samples of the first group) made 35…37%, 38…39% and about 40%.

4 Conclusions

Thus, the tests conducted confirmed the authors' assumption about the considerable impact of the acid solution on the uranium ore strength and, consequently, the stability of exposures and pillars. The determined dependencies should be considered in defining the safe crown thickness when applying the technology of underground block leaching of uranium ores.

So, the research conducted enabled determining the degree of impact of major factors (ore body dip, crown integrity loss caused by technological workings, impacts of reagent used when applying underground block leaching of uranium ores) on the crown stability. These factors should be taken into account when determining safe dimensions of exposures and pillars using corresponding correction factors. As a result, in concrete conditions it is necessary to correct parameters of structural units of blocks, particularly the crown thickness, considering the value of its stability changes caused by the above factors. This correction enables avoiding the crown failure and provides safety of works. The determined dependencies can then be corrected considering practical experience of "VostGOK" underground mines.

So, the research conducted has resulted in the following:

- the degree of impact of major factors (ore body dip, crown integrity loss caused by technological workings, impacts of reagent used when applying underground block leaching of uranium ores) on the crown stability has been determined;
- the factors should be taken into account when determining safe dimensions of exposures and pillars using corresponding correction factors.
- in concrete conditions it is necessary to correct parameters of structural units of blocks, particularly the crown thickness, considering the value of its stability changes caused by the above factors. This correction enables avoiding the crown failure and provides safety of works.

The determined dependencies can then be corrected considering practical experience of "VostGOK" underground mines.

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Study of rock structure properties during combined stopping and development headings

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Abstract. The purpose of this study is to establish the mechanism of interaction between stresses and strains and their quantitative values at the intersection of stopping and development headings to optimize methods for controlling the behaviour of the rock massif. The research complex includes priority methods with experimental confirmation of the calculated parameters by geophysical studies, including stress calculation by a sensor system and surveying levelling to measure deformations using support frames. The properties of the massif and the role of faults and macro-cracks in the development of a field of a complex structure are systematized. A method for studying the stresses and deformations of rocks at the intersection of stopping and development headings is given. The patterns of the rock massif behaviour at the point of intersection are established. The article provides quantitative values of changes in the physical and mechanical properties and stability of rocks at the point of intersection. Massif was differentiated according to the magnitude of the effective stresses in different phases of the intersection. Stresses for specific conditions were calculated with the determination of the reliability of the mining site. The patterns of change in stresses and strains in time are noted.

1 Introduction

The operated deposit is an underground structure with an internal arrangement and a system of elements. The construction parameters are calculated by methods of structural mechanics, which includes the principles and methods for calculating the strength, stiffness, and stability of structures. Structural mechanics is a tool for calculations related to the strength, stiffness, and stability of both individual elements and the structure as a whole [1-3].

The safety of underground structures is assessed by comparing the actual value of the risk with its value, established based on a situation analysis. For the sake of objectivity, comparable construction geotechnologies should be comparable in the maximum number of features: ore reserves, dip angle, ore and gangue rock characteristics, plant production capacity, and cost of operations. When comparing technology, the risk indicator can be determined by one main parameter, for example, by the bearing capacity of a structure from rocks exposed by mining.

The control effect on the strength of the system consists in the use of parameters at which the strength of the bearing rock structures is ensured by the residual strength of the rocks and the stresses of the lateral active rocks pressure, which can be increased by hardening the rocks.

Controlling the strength of the rock structures consists of the implementation of the residual bearing capacity of the rocks by limiting the size of the spans of the workings. Within geomechanically balanced areas, underground and construction geotechnologies minimized in terms of labour and materials costs can be applied.

The greatest danger to underground objects is the critical deformation of the rock mass in the case of insufficient strength of natural or artificially created supporting structures - pillars, which depend on the spans of exposure of the rock roof between the supports. The processes in the rock masses are stochastic, the initial information for solving the technical and economic problems in the mining industry is probabilistic, so the evaluation of the behaviour of the massif and its impact on underground objects is a serious problem, the relevance of which increases with the scale of the expansion of mining in the deep of Earth.

To increase the safety of natural-technogenic structures, the safety margin of the pillars is sought to be increased. This is accompanied by an increase in ore losses in the security pillars and an increase in the cost of materials for the construction of artificial supports.

The underground structural analysis employs general laws of mechanics and proportions that take into account the physical and mechanical properties of the rock mass, the conditions of the interaction of elements, parts, and structure base. According to the measurement results, a

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design scheme for the structure and a mathematical model in the form of a system of recurrent equations are formed. The advantages of structural mechanics in the mining industry include the ability to solve dynamic problems because the underground structure is a system operating under the influence of variable dynamic loads and force fields [4-6]. A prerequisite for the safe and efficient underground exploitation of mineral deposits is accounting for and using the properties of the ore-bearing rock massifs. The quality of the extracted raw materials and the number of expenses for managing rock structures depend on the completeness of property accounting; therefore, the dynamic of stresses and strains in the process of mining ores is the goal of field studies, including geophysical and surveying methods.

The safety and efficiency of mine development are ensured by preventing critical stresses in the elements of the ore-rock-ground system, arising from the interaction of man-made (caverns, explosion seismic, vibration, etc.) and natural (tectonics, gravity, seismicity) factors of field development. The increase in the depth of mining and the increase in mineral extraction enhances the scale of the impact on the ore-bearing massifs, the stability of which is the result of the interaction of the emerging force fields. The most dangerous conditions are created when the ore bed is intersected with workings.

The experience gained in controlling the properties of an array can be reduced to the following:
- in underground mining, fractured rocks have residual strength and are capable of creating supporting structures;
- the use of rock structures during mining is an effective way to improve the performance of underground and construction geotechnologies;
- the reliability of the control of rock masses state enclosing mountain objects is increased by using measures to adjust the sizes of structural blocks by technological means;
- the use of rock structures creates an economic effect, reducing losses entirely and improving the quality of mineral resources extracted, and reducing the cost of labour and materials for the control of rock pressure. The rocks of different ages in the geological structure of rock deposits are involved. The leading role in the structure and ore content of the deposit belongs to faults. Near the tectonic faults, the fracturing increases, reaching a maximum in the operating faults and near them.

The ratio of the dimensions of the permissible span by stability and the span of the collapsed arch becomes a priority safety criterion, especially when mining rocks over a large area, for example, with the leaching of metals from ore deposits. The most dangerous phenomena in the form of loss of stability or dynamic forms of rock pressure occur when the ore is excavated in areas of articulating structural disturbances composed of strong but fractured and weakened rocks. The behaviour of rock masses during development depends on the interaction of natural and technical factors. Natural factors include, first of all, the stresses acting in it at different periods. Research in this area is aimed at predicting the development of rock pressure at the intersection of workings to make timely management decisions and sustainable development.

2 Research methods

The study of rock mass management technologies uses a systematic approach that includes a set of studies: analytical studies based on literature data, field studies (surveying, stress and strain measurements), laboratory tests (modelling of materials) and theoretical (finite element method, thermodynamic, energy, etc.) [7-11].

Considering the uniqueness of each deposit, the priority is given by methods with experimental confirmation of calculated parameters. Applied technologies are divided into various types based on the use of the destroyed rocks residual bearing capacity. The range of studies in this area includes: “Structural analysis”, “Structural dynamic”, “Analytical and numerical methods for structural analysis”, “Stability calculation”.

In underground construction geological and surveying tools are used, including [12-20]:
- stress measurement in lining by strain gauges;
- deformation measurement in lining by levelling (fig. 1).

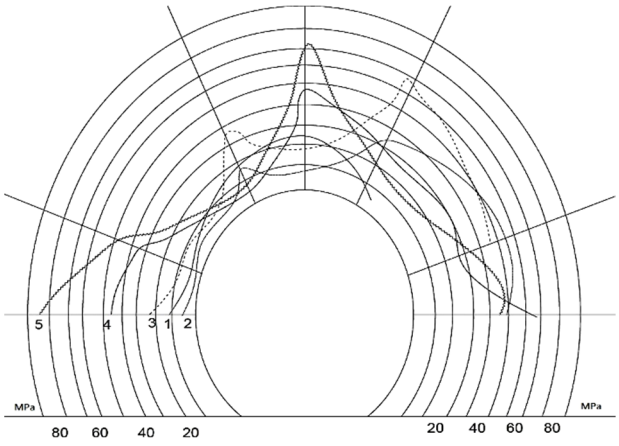

Fig. 1. Stress σ_x distribution diagram of the frame lining for measurements No. 1-5.

The dependences of stresses on time obtained by the authors are described mathematically in the course of analytical studies. The state of the rock masses during mining is monitored by a complex method, including analysis of analogues, calculations using theories of elasticity, plasticity, and transverse deformation, experimental studies using acoustic and electromagnetic emission, seismic sounding, ultrasonic and shock wave monitoring. The basis for successful field development is the combination of the tasks of ensuring geomechanical safety by introducing system monitoring and diagnosing the condition of the rock mass.

System monitoring of the geomechanical state of the ore-bearing massif and underground structures provides continuous monitoring and technical diagnostics. The primary monitoring is the separation of the geotechnical system in the control of individual objects with the synthesis of results to predict the effectiveness of the functioning of the production cycle of the system as a whole. It is a complex of theoretical concepts and a fleet of technical means for their implementation in practice and is carried out using sound metric, surveying, and optical instruments, string tensometers, deep and ground

benchmarks, electrical circuits, visual and indirect methods for changing the salinity of mine water. Establishing a relationship between natural and technological factors makes it possible to clarify the standards of discovered, prepared, and ready for excavation ore reserves under geomechanical conditions.

3 Results

The development of rock deposits increases stress to critical levels with a deterioration in the quality of subsoil use, which increases the urgency of the problem of geodynamic processes control. The maximum stresses develop during the stage-by-stage mining of deposits by chamber-pillar systems in the places of equipment of temporary and permanent pillars and in areas of changing the power of ore bodies.

The level of critical stress here exceeds the average values by 2-3 times. Reducing the level of stress to a safe value is ensured by engineering activities with advanced unloading of massifs. The optimum ratio of ore deflection parameters and stress levels is ensured by using technology optimization techniques based on account of seismic blasting effects on the array and surface objects.

A significant role in the behaviour of ore-massif in underground mining of complex structural deposits, for example, Vostok (Kazakhstan), is played by faults and macro fractures forming fracture and splitting zones of rocks with seams filled with friction clay or quartz-carbonate veins [21 - 28].

The physical and mechanical properties of the rocks obtained (by the authors) by the laboratory and field studies at the Vostok deposit (Northern Kazakhstan) are presented in Table 1.

Table 1. Physical and mechanical properties of rocks.

Characteristic of rocks	Density ρ, g/cm^3	Compressive strength σ_c, MPa	Tensile strength σ_T, MPa	Compressional velocity V_c, m/s	Acoustic impedance, 10^5g/s cm
Andesitic porphyrites	2.80	105.9	8.4	4753	13.4
Quartz porphyry modified	2.87	77.8	3.8	3452	9.9
Quartz porphyry sheared	2.71	26.4	3.4	2612	7.09
Facette conglomerate	2.73	77.0	14.5	-	-
Mineralized siltstone-argillite	2.70	62.0	15.0	-	-

The dynamic of stress changes closer to the ore body was investigated by the strain gauge method. The deformation of the lining was calculated by measuring the distances between the bench mounted on 27 metal frames on a 13 m long section. In the other development, 9 metal frames were installed. The strain gauge station was placed on 5 metal frames in the second development. On each frame 9, measuring points were installed, including individual sensors glued on three planes. Stresses and strains were recorded once a month. According to the measured deformations ε_0, ε_{f1}, ε_{f2}, the main deformations were calculated:

$$\varepsilon_{1,2} = \frac{\varepsilon_{f_2}+\varepsilon_{f_1}}{2} \pm \frac{\sqrt{2}}{2}\sqrt{(\varepsilon_{f_2}-\varepsilon_{f_1})^2+(\varepsilon_0-\varepsilon_{f_1})}, \quad (1)$$

And angle φ between ξ_0 and ξ_1

$$tg\phi_0 = \frac{\varepsilon_{f_1}-\varepsilon_{f_2}}{2\varepsilon_0-\varepsilon_{f_1}-\varepsilon_{f_2}} \cdot tg\phi_1, \quad (2)$$

The principal stresses, according to Hooke's law:

$$\sigma_1 = \frac{E}{1-\mu^2}(\varepsilon_1 + \nu\varepsilon_2), \quad (3)$$

$$\sigma_2 = \frac{E}{1-\mu^2}(\varepsilon_2 + \nu\varepsilon_1), \quad (4)$$

where E – elasticity modulus; ν - Poisson's ratio.

Normal stresses σ_z – vertical and σ_x – horizontal:

$$\sigma_z = \sigma_1 \sin\alpha - \sigma_2 \sin\alpha, \quad (5)$$

$$\sigma_x = \sigma_1 \sin\alpha - \sigma_2 \sin\alpha. \quad (6)$$

The looseness of the massif was determined based on the measurement results. The stress dynamic was measured by sensors of the well walls displacement drilled in the study area [29-32]. It is established that the well walls displacement is a function both of the load intensity and the time of its action (fig. 2).

According to the propagation of deformations, the massif is differentiated into phases:
- in the initial phase of deformation the lining increased from 2 to 16 mm;
- when cutting the ore body from the hanging side, the deformation of the lining increased to 19 mm;
- in the development phase of stopping the lining deformation developed until damage.

With the progress of excavation, the average deformations for 1, 2 and 3 months were: 43, 119, 128 mm correspondingly. The maximum deformations of the lining are noted in frames located close to the clearing face and in the area of the fault. So, after 6 months, the deformations in the upper arch of frame No. 4 were 233 mm, the width of the lining at a distance of 0.5 m from the rocks increased by 55 mm. Frame number I9 failed because the center of its upper arch was lowered by 432 mm, and the width of the locks increased by 312 mm.

The load on the lining of advance workings is connected with the phase of stopping correlatively. As long as the ore body behaves as a beam pinched in the sides, rock pressure is distributed evenly. After cutting the segments from the hanging side, the load on the lining elements from stopping increases (Table 2).

Displacements in the fracture zone (sensor No. 10) are caused by a strong disturbance of the fracture zone rocks with the deterioration of their physical and mechanical properties, which sharply reduces the stability of rocks in this zone. It has been established that pillars between cross

drift equally experience higher deformations than the rock masses even at equidistance from the stope influence (fig. 3).

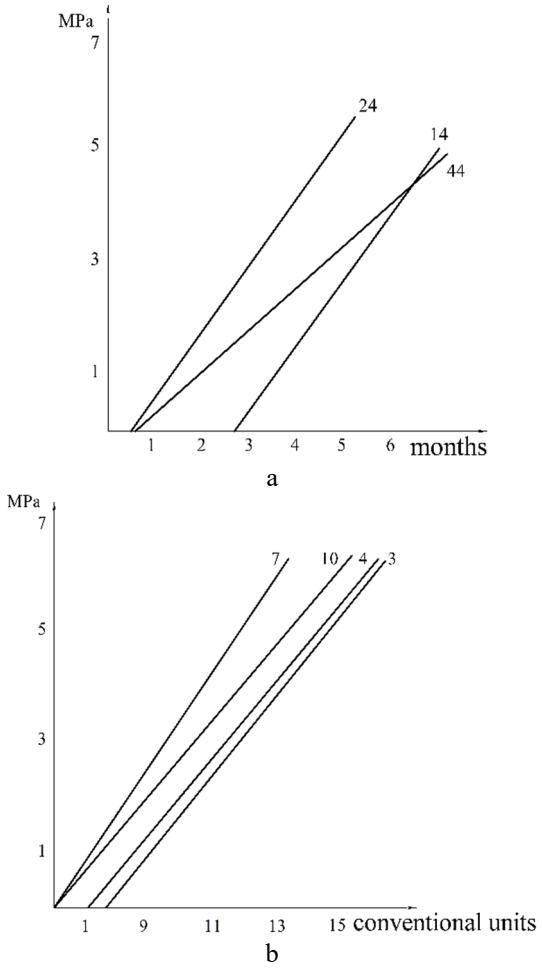

Fig. 2. Sensors indications: a – pressure, b – displacement.

Table 2. Results of stress and strain measurements of the sensors.

Time *t*, months	Deformations *d*, mm				Stresses *σ*, MPa		
	Sensor numbers				Sensor numbers		
	4	10	3	7	24	44	11
1	0.9	0.15	0.24	0.09	-	-	-
2	3.6	0.55	0,21	0.22	2.3	0.12	0.04
3	-	2.2	0.26	0.24	9.7	2.35	0.85
4	-		0.50	0.26	7.65	5,1	2.65
5	-		0.90	0.62		6.35	3.6
6	-		1.00	0.8		-	3.7

Three sections of operating stresses characterize the massif. A slight increase in stress characterizes the initial section. With the approach of the sewage treatment front and the increase subsurface mining area, the ore massif is experiencing an increasing load.

The ratio of rock load above the exploited space and in the stress concentration zone or the pillar presents the information about the massif geodynamics. During the actual mining over the area of length *L* and width *I* there is a load *Q* caused by the mass of overlying rocks (γH):

$$Q=L_1\gamma H \quad (7)$$

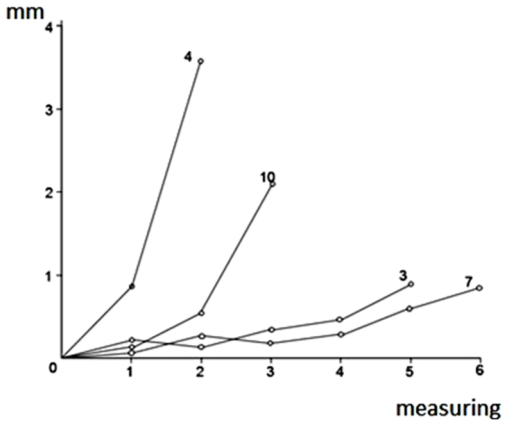

Fig. 3. Well walls displacement in time for sensors No 3, 4, 7, 10.

The magnitude γH, in this case, is 98 MPa. If we allow that the mining effect extends to the same length l, then the load is:

$$Q = Q_1 + Q_2 \quad (8)$$

where Q_1 is the overlying caved rock load, Q_2 is the load caused by technology.

The load growth in the area of stress concentration in specific conditions is 15-20 % of the gravity component and 39 MPa that is less than the compressive strength of rocks - 54-75 MPa.

The monitoring of the rock mass state by the displacement sensors 3, 7 and pressure sensors shows a slight increase in strain and stress during the first three months of actual mining. Only after three months, the influence of cleaning works is seen. Rock mass stresses increase slower than in the ore. At the end of the actual mining, the stresses and strain in the massif stabilize.

When combining stopping and development headings, their allowable sizes depend on the roof rock behaviour. If structural blocks of rocks are shifted into the developed space, the roof takes the form of a vault. In this case, adding waste rocks worsens ore dilution and losses of metals in the ore dressing, that is why the aim is to save flat roof choosing the work options at which the rocks in the lower layer wedge and hold rock load inside the vault of natural balance (fig. 4).

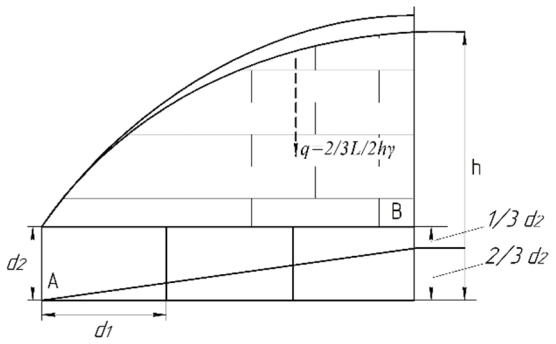

Fig. 4. The condition for the formation of a flat roof: *h* – is the height of the arch of equilibrium; *L* – is the span width; d_1 – is the length of elementary structure; d_2 – is the height of structural units; *γ* – is the volume weight of rocks; *q* – is the

moment of force, A and B – are the edges of the arch of equilibrium.

Vetrov-Golik model describes this condition:

$$L_{max} = 2d_2\sqrt{\frac{10R_{com}}{K_2\gamma d_1}} \quad (9)$$

where L_{max} – the maximum span of the flat roof; d_1 – the horizontal size of structural blocks, m; d_2 – the vertical size of structural blocks, m; γ – volume weight of rocks; K_2 – safety factor.

If the roof is composed of rocks, deformations in which do not exceed the plastic limit, the allowable span of the flat roof is determined from the equations:

$q = \frac{L_0 h_0}{3}$; $h_0 = \frac{L_0}{2V_0}$; $q = \frac{L_0}{2V_0}$; $M_q = \frac{L_0\gamma}{18V_0}$; $T = \frac{10R_{com}}{R_c}\frac{1}{2}d_{oc}$;
$M_T = T\frac{5}{2}d_{oc} = \frac{10R^o_{com}\cdot 5d_{oc}}{18K_2}$; $R_{com} = R'_{com} = R^n_{com}$.

The width of the flat span can be increased, fastening the structural rock blocks by anchors, concrete, etc.:

$q_н = \frac{L_3 b\gamma}{2}$; $M_q = \frac{{L_3}^2 b\gamma}{8}$; $T = \frac{10R_{com}}{K_2}\cdot\frac{2dn_2}{3}$;
$M_T = \frac{10R_{com}\cdot 10d^2 n_2}{18K_2}$; $L_3 = 298dn_2\sqrt{\frac{10R_{com}}{K_2\gamma_б}}$.

The efficiency of using rock structures in the operation of underground structures is achieved by improving the quality of mined ores and the safety conditions of workers [15-18]. The crushing of distinct rock blocks is a critical component of optimizing the technology for extinguishing the developed space, which makes it possible to develop deposits with an environmental and economic effect while ensuring the safety of mining operations.

In underground mining of rock ore deposits, the phenomenon is realized by constructing the boundaries of the area of dangerous displacements in the rock mass using geophysical research methods. Geophysical monitoring of field development processes allows us to assess the state of the system and the stress-strain state of the rocks, which allows us to assess the stability of the massif under various conditions of void formation.

The proposed approach can be used to detail working projects for managing the state of ore-bearing massifs of rock deposits of complex structure.

4 Conclusions

In the process of intensive intervention by mining operations, the ore-bearing massif the structural units of rocks are destroyed and come into contact with each other, often with the creation of jammed systems.

Under certain conditions, emerging structures are used to control the geomechanics of a given section of the earth's crust. The adequate nature of this phenomenon, which can be observed during ore production, allows predicting the behaviour of rock masses with sufficient detail to control the ore-bearing mass, which allows adjusting the development parameters to obtain the economic effect of improving the quality of mined ores and reducing the risk for workers. The efficiency of using rock structures consists of saving labour and materials for controlling the state of rock masses during underground work.

In underground mining of ore deposits, the dynamic of stresses and strains at the intersection of stopping and development headings can be predicted with sufficient detail to control the ore-displacing massif, which makes it possible to adjust the development parameters with the economic effect of improving the quality of mined ores and reducing the risk for workers.

The novelty of the proposed method for predicting the dynamics of rock pressure is the use of mechano-structural properties of discrete structural rocks, in contrast to most methods based on the mechanics of a continuous medium, which brings the calculation results closer to the actual position of the massif.

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Machine learning: technologies and potential application at mining companies

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Abstract. Implementation of machine learning systems is currently one of the most sought-after spheres of human activities at the interface of information technologies, mathematical analysis and statistics. Machine learning technologies are penetrating into our life through applied software created with the help of artificial intelligence algorithms. It is obvious that machine learning technologies will be developing fast and becoming part of the human information space both in our everyday life and in professional activities. However, building of machine learning systems requires great labour contribution of specialists in the sphere of artificial intelligence and the subject area where this technology is to be applied. The article considers technologies and potential application of machine learning at mining companies. The article describes basic methods of machine learning: unsupervised learning, action learning, semi-supervised machine learning. The criteria are singled out to assess machine learning: operation speed; assessment time; implemented model accuracy; ease of integration; flexible deployment within the subject area; ease of practical application; result visualization. The article describes practical application of machine learning technologies and considers the dispatch system at a mining enterprise (as exemplified by the dispatch system of the mining and transportation complex "Quarry" used to increase efficiency of operating management of enterprise performance; to increase reliability and agility of mining and transportation complex performance records and monitoring. There is also a list of equipment performance data that can be stored in the database and used as a basis for processing by machine learning algorithms and obtaining new knowledge. Application of machine learning technologies in the mining industry is a promising and necessary condition for increasing mining efficiency and ensuring environmental security. Selection of the optimal process flow sheet of mining operations, selection of the optimal complex of stripping and mining equipment, optimal planning of mining operations and mining equipment performance control are some of the tasks where machine learning technologies can be used. However, despite prospectivity of machine learning technologies, this trend still remains understudied and requires further research.

Topicality of the research consists in the fact that at present many mining companies are facing the necessity of increasing efficiency of their performance in conditions of rising competitiveness and market globalization. To achieve the set goals, it is essential to reduce costs, optimize use of equipment and human resources.

Mining companies often implement technological process control systems where a great amount of current information on their production processes is stored. This information is used directly for operating control and management. The practical value of the accumulated information in the long term mainly consists in statistical reporting.

In view of the above, a need arises to use the accumulated information for identifying segments of technological processes of less efficiency. To do this, means of machine learning technologies may be used.

Machine learning focuses on development of applications and specialized algorithms capable of self-learning and adapting. Application of machine learning algorithms enables processing data to search for relevant patterns and change programme actions.

The article aims to study technologies and potential of machine learning at mining companies.

To reach the set research objective, the following *tasks* should be accomplished:

– to reveal the essence of machine learning;

– to describe machine learning algorithms;

– to provide an example of a subject area of machine learning application at mining companies.

Despite the tremendous development of machine learning technologies in the recent decade, artificial intelligence remains a rather ambiguous concept. It includes a number of subject areas: from generation of plausible images on a certain theme to prediction of time series. Methods of machine learning are the basis of artificial intelligence technologies but remain a highly tailored solution to every particular task.

Machine learning is a sub-division of artificial intelligence dealing with methods of elaborating algorithms capable of finding dependencies in data and

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learning. Learning from examples is based on identification of patterns by individual empirical data. Deductive learning is implemented through formalization of expert knowledge and its transfer to the knowledge database [3].

S. A. Shumskiy suggests creating strong artificial intelligence using principles of the human brain work and does a review of the current state and prospects for further investigations into machine intelligence [12]. Only machine learning supported by the achieved level of computer capacities is able to make machine intelligence fast soar to the human level and engage these capacities into solving the problems only people can manage.

Methods of machine learning include: supervised learning, unsupervised learning, action learning, semi-supervised machine learning [11].

Supervised learning is implemented through inputting data into a machine and their preferable outputting, objects called "a teacher". Its objective is to study the general rule which will enable displaying input data at output. Algorithms like that use everything they have learned earlier when dealing with any new data.

Many types of learning are based on the generalizing transition from training data to new data through studying similarities between them. In grouping models, which include, in particular, decision trees, such similarity takes on the form of equivalence relation, or object-space splitting: two objects are considered similar if they are in the same segment of splitting [10].

Unsupervised learning assumes that labels, tags or explanations are not transferred to the learning algorithm with respect to the input, and it remains as it is, for searching for a relevant structure in it. Such algorithms are used to find hidden patterns in data arrays and draw one's own conclusions or conclusions from the data obtained from data sets.

In practice, learning is implemented through direct interaction with the changing environment and is to fulfil a certain task (e.g. operating a vehicle, equipment positioning) without informing whether it is reaching the destination or not.

Semi-supervised leaning means that the subject "teacher" gives the machine data with certain drawbacks, and results are not obtained.

Use of a particular method of machine learning is conditioned by the subject area of its practical application. The most preferable methods of machine learning are supervised learning, unsupervised learning that enable solution of most tasks of mass data processing.

Matrices, graphs, probability, function, gradient, minimum of function, optimization, error are the most popular objects of neuromathematics that are frequently used in machine learning.

The array of source data in a particular neural network is the most illustrative example of practical application of a matrix (a table of numbers) [5]. Fig. 1 presents the generalized chart of a single-layer perceptron that recognizes digits.

The perceptron consists of three types of elements, namely: incoming signals from sensors, associative elements and responders. Thus, perceptrons allow creating a set of "associations" between incoming stimuli and the required output response.

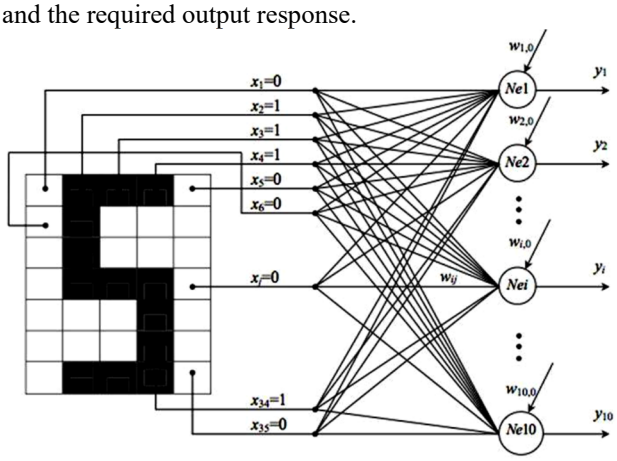

Fig. 1. A single-layer perceptron.

In the modern terminology, perceptrons may be classified as artificial neural networks:

– with a single hidden layer;

– with a threshold transfer function;

– with direct signaling.

Another object, a graph, is a set of vertices and a corresponding set of connections between them. It is a good visual mathematical object depicting a model chart or an algorithm structure.

In mathematics, a graph is often represented by an ordered pair $G=(V, E)$, where V is a set of vertices, E is a set of edges linking these vertices.

The given diagram shows that the source image may be presented as a corresponding 7-by-5 matrix consisting of ones and zeros, Fig. 2.

$$\begin{pmatrix} 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 \end{pmatrix}$$

Fig. 2. A matrix of perceptron values.

Various calculations that can be performed on such a graph enable finding, for instance, the shortest bypass road or the nearest handling facilities, planning the optimal haulage route, etc.

Description of links between objects with the help of graphs is implemented through associating edges to certain quantitative values, qualitative attributes or required characteristics called weights. In the simplest case, this can be an edge sequence numbering showing the order of their direct consideration (priority or hierarchy of events).

The graph edge weight may depict:

– the haulage route length (transportation);

– bandwidth (communication);

– voltage or current strength (electric circuits);

– the conductor colour in the wiring diagram of an electronic device;

– the amount of work completed (production);

– link valences (chemical formulas), etc.

When assessing machine learning, the following requirements are considered: speed of operations; assessment time; implemented model accuracy; ease of integration; flexible deployment within the subject area; ease of use; result visualization.

Application of machine learning technologies in the mining industry is a promising and necessary condition for increasing mining efficiency and ensuring environmental security. However, despite prospectivity of machine learning technologies, this trend still remains understudied and is not yet implemented to the required extent.

According to M. B. Nosyrev, A. V. Druzhinin and N. B. Glushenko, increased efficiency of mining companies' performance depends on arrangement of coal mining by the open pit method. Unique machinery used here and sophisticated technologies require practical application of intelligent technologies and simulation of mathematical models when designing, planning and controlling the life cycle of a coal pit [6].

One of the solutions to these tasks consists in transferring the expert system technology into the artificial intelligence sphere of industrial information management systems. Traditional problem areas for expert systems are: identification and diagnostics used for situation interpretations; prediction used for determining probable sequences of the identified situations and states; planning for elaborating goals and adaptive control for achieving the set goals.

Here, application of machine learning technologies enables obtaining qualitatively new knowledge based on which the following tasks can be accomplished:

– selection of the optimal process flow sheet of mining operations;

– selection of the optimal (by basic characteristics) complex of stripping and mining equipment;

– optimal operational planning of mining operations and mining equipment performance control;

– useful minerals quality;

– life of mine;

– completeness and quality of useful mineral extraction and processing;

– mine field sizes;

– the designed depth of open pit and underground operations;

– pmining elements sizes (level height, sizes of blocks, panels, rooms);

– the period of construction and exploitation of the designed deposit thickness.

The above classification shows that current formal prediction and control models in mining cannot always be adequately applicable at a mining enterprise and cause the necessity of developing new approaches to creating systems on the basis of machine learning technologies.

For instance, V. N. Soloviev et al. investigates methods and algorithms used at solving problems of assessment, regression and filtration, image recognition and clusterization [8]. The considered classic and modern implementations of machine learning algorithms can be applied to solving tasks of processing data of a particular subject area.

A. O. Zibert and V. V. Miroshnichenko set the task of applying machine learning algorithms to increase efficiency of truck performance. They provide description and give an example of practical application of the perceptron model to predicting performance periods without maintenance-caused outages based on the classification of such performance periods [4].

The authors also provide detailed description of training data and the method of generating these data from the database, consider the results of the perceptron model application and conclude on possible application of the used model to solve machine learning tasks.

The intellectual mining-engineering system should continuously identify and monitor characteristics of a controlled object. Feedback and availability of a reliable automated control system are also required. Such systems are always controlled under conditions of principal uncertainty of development and incomplete observability. Building formal models for most processes of a mining company is extremely complicated.

In view of the above, it is necessary to implement machine learning systems at mining companies considering interaction of various production components including engineering, technological and socio-engineering mining objects.

According to I. O. Temkin and A. N. Goncharenko, there currently exist many intellectual models, methods and technologies widely used in controlling complex industrial objects and socio-engineering systems: data mining; fuzzy logic; probabilistic prediction models; neural network models of situation recognition; genetic algorithms; knowledge acquisition; natural language processing; search for solutions in conditions of insufficient information provision [9].

Another problem that can be solved with the help of machine learning is engineering research during building of complex engineering systems (F. N. Abu-Abed [1, 2]). Timely recognition of pre-emergency situations that can occur during operations may provide production stability and safety. A pre-emergency situation is an emerging process different from the regular one and requiring a prompt response. The largest problems in timely detection and identification of pre-emergency situations occur in a complex engineering system during its building.

Examples of complex engineering plants include drilling rigs for oil and gas wells drilling, radars and other complex engineering systems. Complications are caused by:

– the necessity of operational visual control over current technological processes in the system;

– the necessity of making relevant decisions and subsequent production of recommendations in the real-time mode in conditions of insufficient information;

– the necessity of operational accounting of a large quantity of initial data and diverse factors;

– insufficient qualification of some enterprise employees [1; 2].

In recognizing pre-emergency situations occurring during the trial operation of systems, the number of attribute space dimensions is rather big and boundaries

between pre-emergency situation classes are blurred. Application of cluster analysis and Bayesian classification to solving the task of pre-emergency situations recognition during well drilling is not reasonable. With this purpose, artificial feedforward neural networks capable of being taught through practical use of the back propagation algorithm may be used as a mathematical tool for solving the pre-emergency situations recognition task.

Many mining companies apply dispatch systems and machinery monitoring. The automatic system of controlling mining and transportation complex "Quarry" of VIST Group is an example of such a system [7]. Fig. 3 presents the system architecture.

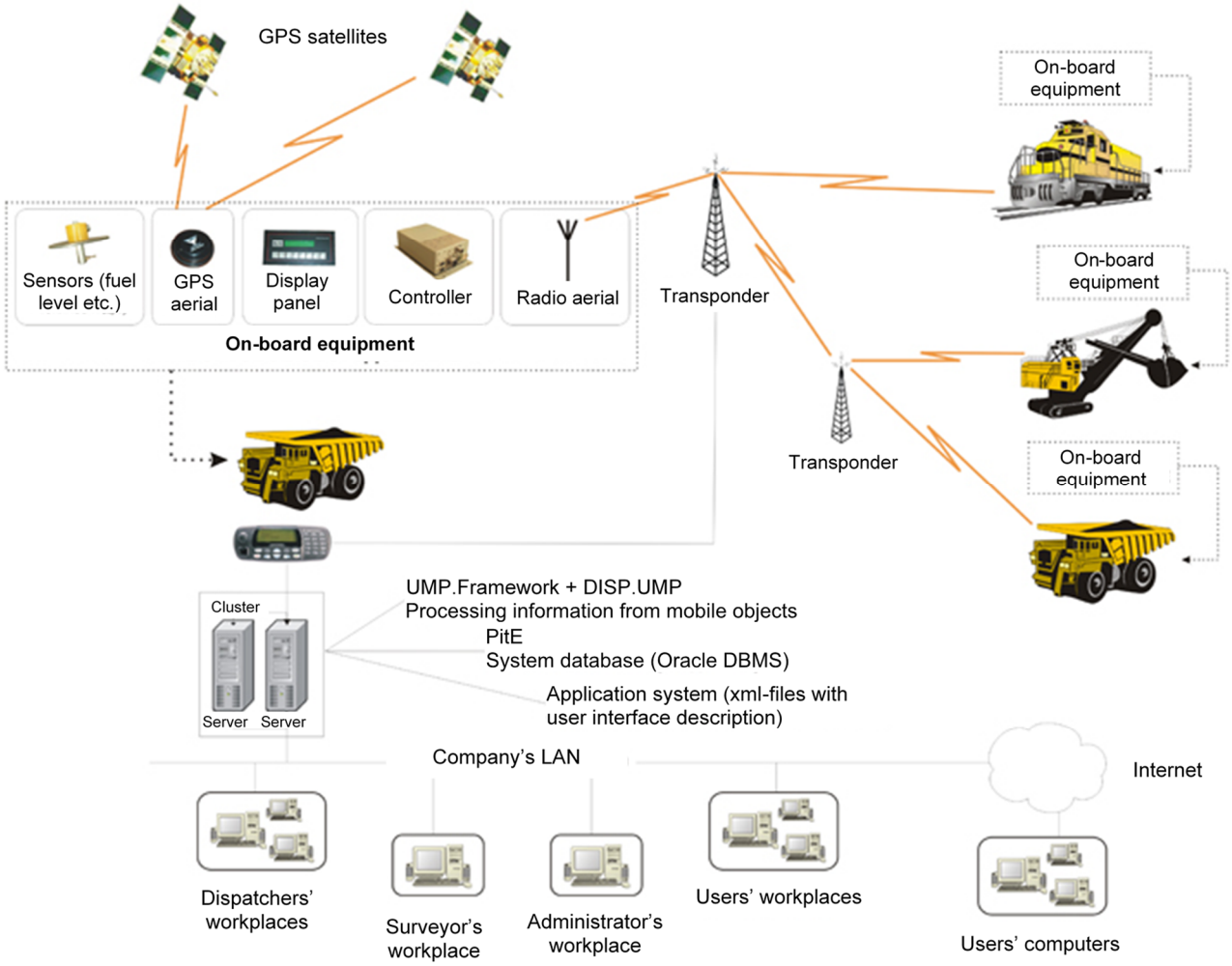

Fig. 3. Architecture of the automatic system "Quarry".

The automatic system "Quarry" receives data from the following sensors:

– sensors of machinery position, speed and route (GPS);
– handled ore mass weight sensors;
– excavator bucket position sensors;
– pressure sensors in the bulldozer turbine;
– truck wheel pressure sensors;
– excavator operation currents sensors;
– fuel level sensors.

The information users are:

– the dispatcher control room of an enterprise, various users of the enterprise local network;
– other engineering services of an enterprise – statistics on real equipment performance, stand-by time, kilometers travelled, handled material volumes.

Besides, it is possible to detect equipment stand-by time or determine periods of its most efficient performance on the basis of the collected information.

However, due to a great amount of the information processed, analysis of historical data is rather labour consuming. To eliminate the problem, various data processing algorithms should be used to enable prompt analysis of causes of inefficient equipment use and search for ways of reducing the number of and preventing such situations.

As the initial data for the set goal of increasing efficiency of mining equipment use are rather similar to the presented examples of machine learning use, one may say about use of machine learning algorithms for determining the optimal mode of mining equipment performance based on dispatch system data as well as determining factors impacting efficiency of mining equipment use.

To estimate the above assumption, one can use the perceptron-based algorithms of machine learning through

comparing the obtained predictions with the real data. The perceptron consists of three types of elements: signals from sensors, associative elements and responders. Thus, perceptrons enable creation of a set of "associations" between the incoming stimuli and the required output response.

The perceptron performance may aim at creating the following classification of mining equipment:

– class 1 – probability of mining equipment stand-by caused by possible maintenance within the following 30 days makes 100%;

– class 2 – probability of mining equipment stand-by caused by possible maintenance within the following 60 days makes 100%;

– class 3 – probability of mining equipment stand-by caused by possible maintenance within the following 90 days makes 100%;

– class 4 – probability of mining equipment stand-by caused by possible maintenance within the following 120 days makes 100%;

– class 5 – probability of mining equipment stand-by caused by possible maintenance within the following 150 days makes 100%;

– class 6 – probability of mining equipment stand-by caused by possible maintenance within the following 180 days makes 100%.

The following information on mining equipment stored in the dispatch system database may be input into the perceptron model:

– average rate of mining equipment performance (km/h) per shift;

– average energy consumption per shift;

– average inclinometer reading value (degrees) per shift;

– average temperature (degrees centigrade) per shift.

However, mining production possesses a number of specific features that condition complexity of implementation of formal methods and models of control.

The first and the most significant feature of a mining company is production which is discrete-continuous in character. The second but not less important feature is a specific controlled object – nature (parameter distributability, process stochasticity, etc.). Another feature is specificity of the control system which includes complex functional blocks, such as survey, geological, etc.

Thus, based on the obtained results, the following conclusion can be drawn: it is possible to apply machine learning algorithms to enhancing efficiency (in the medium term at least).

Besides, further investigations are required, in particular into application of other machine learning algorithms and enhancement of initial data for obtaining better results of an algorithm operation. Another direction of research is application of machine learning technologies to prediction of not only stand-by periods but also efficiency of a mining equipment unit in the short, medium and long term, etc.

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The study of the lining layer abrasing wear in the semi-autogenous grinding mill

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Abstract. In this work complex investigations of the abrasing wear of lining of self-grinding mills (semi-autogenous grinding mills) are carried out with the obtaining of mathematical models of wear-abrasing of elevators in terms of height, weight, volume and worn-out area. In particular, according to the location and nature of the abrasing wear processes, the liner-lifters mill self-grinding are identified in three typical groups. During 1 year, in the conditions of Ingulets GOK, the monitoring of the abrasing wear of selected groups of lifters of self-grinding mills was performed. On the basis of the experimental data calculationed in the Microsoft Office Excel program, a set of mathematical models of lifter abrasing wear was obtained in terms of height, weight, volume and worn-out area. The obtained dependencies are recommended for prediction of abrasing wear of lining and necessary frequency of replacement of inserts-lifters. In addition, the research of wear of lining made of cast iron RF–4, showed a significant reduction in their abrasing wear compared with steel 110G13L. Thus, it has been shown that the selection of liner-lifters materials can reduce the inter–repair period by 3 times or more (replacement of worn-out lifters). A comparison of the actual picture of the abrasing wear of elevators and Simulation Statics simulated result (using SolidWorks) stresses shows the convergence of the arrangement of the zones of maximum stresses and the maximum abrasing wear of the lining. Investigation of the influence of the stressed state of lining plates on the intensity of their abrasing wear – a promising direction for further research.

1 Introduction

The process of destruction (grinding and crushing) of mineral raw materials is the most energy-intensive and labor-intensive technological operation of ore dressing [1–3]. Investigation of the energy intensity of the processes of ore preparation, including the disintegration of ore, which was carried out in Eastern Europe in 14 mining ore dressing plants that process different raw material physical and mechanical properties, show that 50–70% of the total ore disintegration process accounts for 50–70% expenses, while the electric power consumption for grinding is on average about 60%, and for crushing only 5% [4–6]. It actualizes the research of equipment and technology of milling minerals.

From the end of the twentieth century semi-autogenous grinding (SAG) of ores is the most progressive technology of ore preparation in world practice. As of 2010, in the world mining industry, about 200 large mills of full or partial SAG were in operation, including about 100 of them working in the iron ore industry, 30 in copper, while others – in dressing ore of rare and noble metals. In comparison with grinding in rod and ball mills SAG is characterized by a number of advantages:
- stages of middle and small grinding are excluded;
- saving of crushing bodies (balls and rods are not used);
- there is no contamination of the crushed material with metal;
- improvement of technological indicators of further dressing due to better disclosure and less sludge formation;
- in the processing of gold–bearing ores followed by cyanide losses of gold with iron scrap and crumbs are eliminated, the consumption of cyanide is reduced and the working conditions on quartz and silicone-sensitive ores are improved;
- when flotation of molybdenum ores, the use of SAG (self-grinding) mills improves the dressing rates associated with less "molten" scaling of molybdenite [1, 5–8].

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The critical nodes of semi-self-grinding mills from a techno-economic point of view are drum lining, bearings, washing drum, gear gears of power drives (Figure 1), which account for 70–90% of operating costs [5].

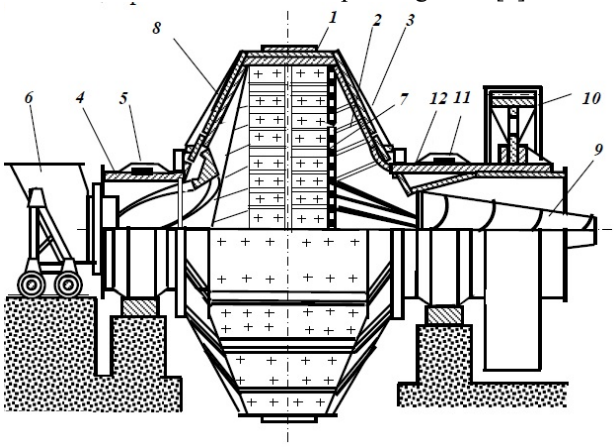

Fig. 1. The mill is a wet type of self-grinding type "Cascade", a general view: 1 – drum; 2 – lifts; 3, 8 – face caps; 4 – boot pin; 5, 11 – bearings; 6 – boot device; 7 – grating; 9 – washing drum; 10 – crown gear; 12 – unloading pin.

Of these, more than 50% – the proportion of lining (its cost, the cost of installation work, planned idle time). Therefore, durability and reliability of lining is a topical scientific and technical problem.

The process of abrasing the lining is determined by the energy of mechanical influence on it from the ore, the strong characteristics of the lining itself and miling ore. Proceeding from this, the following factors significantly affect the abrasing wear of the lining:
- the size of the lumps of the original material;
- maximum mass of ore lumps;
- durability and wear resistance of lining material;
- height of fall of ore lumps (pieces);
- sliding of the rock mass on the lining, which is determined by its profile;
- degree of filling of the drum mill and its frequency of rotation;
- properties of ore: strength, abrasiveness, and in the case of wet grinding – also the density of the pulp.

The lifts in the mills play two important functions – first, it is protection against the wear of the mill shell. Secondly, it is ensured that the ore is raised, when they rotate the drum, they capture pieces of ore, lift them to a certain height, falling from which the ore is self-milling. Therefore, the efficiency of the process of SAG ore in the mills depends to a large extent on the design, location and serviceability of lifters.

2 Literature review

Many researchers have investigated the processes of abrasing wear of the lining of the semi-autogenous grinding mills and the impact of wear-abrasing on the technical parameters of the milling process. In work [9] the effect of lining liners wear on the productivity of the mill was studied. An analysis of fully worn and new inserts-lifters was conducted, as it was in line with the major changes in the mill's operating conditions. It has been found that worn-out mills are more prone to obtaining fine classes, possibly due to the reduction of strong collisions with high impact energy. When abrasing lining material is ground mainly in cascade mode, and with the new lining – in the waterfall mode. Consequently, the wear of inserts-lifts affects the mill operation. Cascade mode (worn out elevators) causes an increased throughput of the mill at lower power.

In [10], the demolition of liners made from martensitic Cr–Mo steel was investigated. It has been shown that the replacement the WS–7HM (400 Brinell hardness) material on WS–222 (Brinell 500) material resulted in a 61% lengthening lifespan lifespan, a 38% reduction in the consumption of liner and a 7% overall material. In addition, the heterogeneity of the wear of the liners was discovered and their rational form was proposed, which takes into account the location in the working space of the mill.

In the paper [11], based on experimental studies and long-term observations, a quantitative assessment of the impact of wear on the liner-lifters on the milling performance itself was made. At the investigated mill there was an increase in the throughput of 10.5% over the life of the elevator. Separate effects of wear of the lift have also been isolated. It is established that increasing the throughput due to the wear of the liner can be further divided into the following components:
• an increase in the lattice diaphragm, 5.3%;
• an increase in the diameter of the mill, 3.2%, and
• a change in the profile of the insert, 2.0%.

D. Royston summing up the experience of Royston Process Technology Pty Ltd. and others. indicates that, taking into account studies of lifts of mills, self-milling for deterioration for their manufacture, the following main materials are used: heat–treated chromium–molybdenum (Cr–Mo) alloyed steel (hardness about 350 Brinell), bimetallic inserts using an "white iron" insert that can provide increased wear and tear in places prone to abrasion (end lining). In addition, polymeric rubber products that provide structural stability can be used as inserts [12].

In work [13] a modification of the form of an insert-lifter SAG was performed based on the 3D measurement of the wear profile of the insert. Experimentally, with the help of a specially designed measuring device it was established that the wear profile is not homogeneous. When finding the appropriate models that accurately described the wear rate of the liners, in order to achieve an even profile of the liner when removing the elevator, new designs of the liners were proposed. This not only increased the lifetime of the elevator, but also reduced the content of scrap metal. Application of the proposed method in the SAG mill 9.75 × 4.88 m showed that the wear profile of the insert along its length was uneven and the highest wear was between 1.25 m and 2.75 m in length of the shell of the mill. The proposed liners, unlike the standard type, did not have a uniform shape, and the height of the liners increased from 152 mm to 187 mm in the area where the wear rate was high. It is established that this new profile comes to a uniform profile at the time of insertion change. Such a technical decision has reduced

the amount of scrap to 30% of the current value of 47%, and on average lifetime of the liner will increase by 1500 h.

A similar approach to the retention of rational form of lining is also used in work [14]. Forecasting the evolution of the shape of the liner and changing performance during the lifecycle lifter allowed to offer a rational form of lifters. Forecasting of the dynamics of wear of elevator is done by the method of discrete elements (DEM). An analysis of the life cycle of the insert has shown a 20% reduction in power consumption, since increasing the volume of the SAG working chamber and blurring the profile of the lifts leads to less efficient mill operation.

At the same time, now is a lack of real comprehensive research on the wear of lining of SAG mills with the simulation of wear and abrasing of elevators in terms of height, weight, volume and worn-out area.

3 Research objective and tasks

The purpose of this article is a comprehensive research on the wear-abrasing of lining mills of the same milling with the obtaining of mathematical models of wear-abrasing of elevators in height, weight, volume and worn out area. To achieve this goal, the following research objectives are formulated:

– in the actual conditions of the Ingulets GOK to monitor the wear-abrasing of lifters of mills for self-grinding. According to the results of the monitoring, identify the typical groups of lifts-lifters;

– on the basis of the experimental data calculation in the Microsoft Office Excel, to obtain a set of mathematical models of lining of the elevators in terms of height, weight, volume and worn-out area;

– to analyze the wear of lifters made of steel 110G13L and cast iron RF–4;

– using the SolidWorks software simulation statics module to investigate the mechanical stresses in the work area of the lifters and compare the data with the actual picture of data of their wear.

4 Basic stages and research results

In the conditions of the preparation plant Ingulets GOK preparation plant (Kryvyi Rih iron ore basin, Ukraine), the nature and patterns of abrasing wear of MMS–70–23 mills were investigated. In this case, elevators made of 110G13L steel, by location, were divided into three groups (Figure 2):

I. Lifts No. 2 and 3, located on the end wall of the loading;

II Lifts No. 5, located on the shell;

III Lifts No. 7 and 8, located on the end wall of the unloading.

In addition, on a pilot sample mill MMS–90–30 the durability of lifters from cast iron RF–4 and SS alloy was investigated.

In researches in work the experimental researches of wearing of lining of mills of self-grinding in industrial conditions of mining complexes of Kryvyi Rih basin which generally lasted for more than 1 year were used. The experimental data processing is done in the Microsoft Office Excel resource with the obtaining of mathematical models of polynomials and abrasing wear curves of elevators in height, mass and volume abrasing wear of elevators from the amount of processed ore and depending on the duration of their operation.

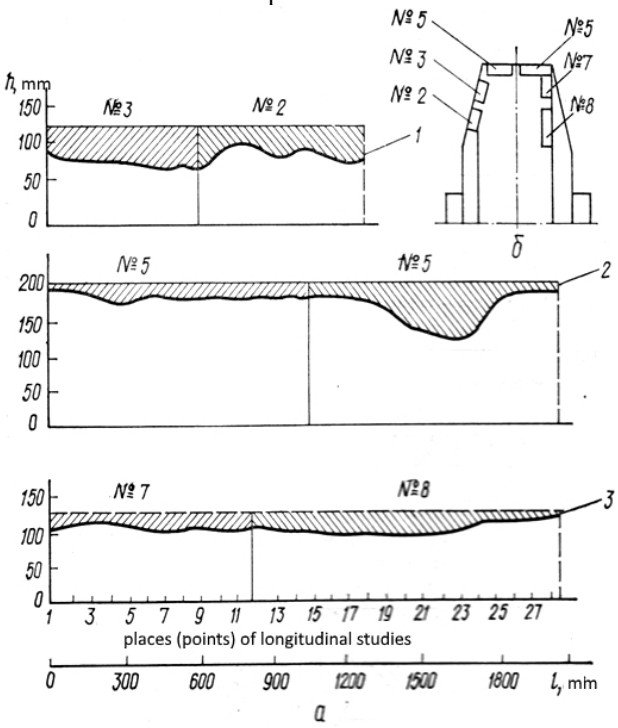

Fig. 2. Wear of lifters of mills MMS–70–23 at height *h* of a working surface (*a*) and a scheme of their location in a drum (*δ*). *l* – the metric size of elevators.

4.1 The first stage of research

The wear of lifters was measured at intervals of 1–1,5 months. The height of their working part and (h, mm) and volume (V, cm^3) was measured. In this case, the period of work of lifters and the volume of processed miner's mass were recorded. Elevators were measured at several points (Figure 2). The last measurement was carried out after processing 200 thousand tons of ore.

Let's analyze the results. As you can see from Fig. 2*a*, lifters number 2 and 3 wear out basically evenly. The maximum wear is observed at the junction – here the height of their working part decreases from 125 to 75 mm.

Lifts No. 5 wear out very unevenly. The greatest deterioration is observed on the elevators located on the side of the discharge – here they wear about half their height. The fact is that in the drum mill near the discharge grid there is an increased circulation of crushed rock mass, which also causes the heavy wear of these elevators before the unloading lattice.

The wear of lifters number 7 and 8 is uniform throughout their length, maximum wear in height – 30–35 mm.

4.2 The second stage of research

For an in-depth study of the wear of elevators of selected

groups I–III, their height was determined depending on the amount of processed mass. According to experimental data analize in the Microsoft Office Excel, curves of wear and tear of elevators and mathematical polynomial models are obtained in height from the amount of processed ore of Figure 3.

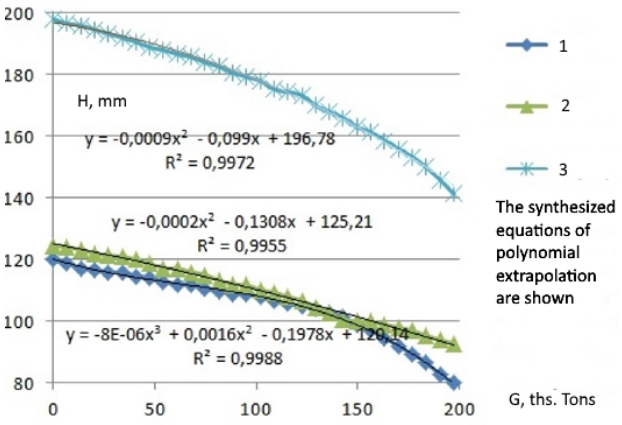

Fig. 3. Dependence of lifters wear in height H (mm) on the amount of processed ore G (ths. tons). 1 – lifts No. 1 and 3; 2 – lifts No. 5; 3 – lifts No. 7 and 8.

The analysis of the obtained data shows that lifters No. 1 and 3 on the part of loading and No.7 and 8 on the part of unloading in height wear out with the same intensity before the processing of the first 120 thousand tons of ore. After that, the intensity of wear of lifters number 1 and 3 increases and after processing 200 thousand tons of ore their average height is almost 20 mm less than the height of lifters number 7 and 8. This, obviously, can be explained by the result of the action on the lifters by loading more large and abrasive lumps of ore than by unloading.

As measurements show, lifters number 5 wear out more intensively and after processing 200 thousand tons of ore, the average height of their working part decreases from 195 to 140 mm.

4.3 Third stage of research

Investigated the massive and volumetric wear of elevators. The results are shown in Figure 4 – dependence of mass and volume wear of lifters on the amount of ore processed G, ths. tons (and corresponding polynomial mathematical models).

The analysis of the obtained model curves shows that lifts number 5, 7 and 8 throughout the life of the service are worn evenly and after processing 200 thousand tons of ore their wear reaches 140 and 120 kg, respectively.

Lifts No. 1, 2, and 3 are worn less intensively before the processing of 100 thousand tons of ore, after which the intensity of their wear increases sharply and reaches 105 kg by the end of its lifetime.

4.4 Fourth research phase

The dynamics of the expansion of the conditioned wearing lining area S_{sn} was investigated, depending on the amount of ore processed G, ths. tons.

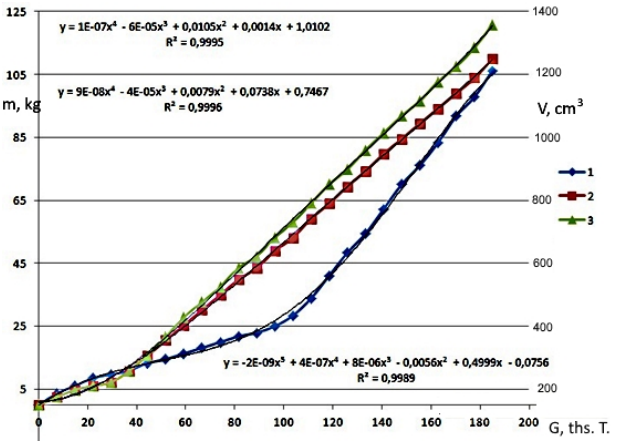

Fig. 4. Dependence of mass (kg) and volumetric (cm^3) wear of lifters on the amount of processed ore G, ths. tons. 1 – lifts No. 1 and 3; 2 – lifts No. 5; 3 – lifts No. 7 and 8.

For this purpose, the amount of wear was divided into a height of wear for a particular elevator. For example, for elevator No.5 (S_{sn5}) using the corresponding polynominal models we find:

$$S_{sn5} = \frac{-0{,}0001x^3 + 0{,}0506x^2 + 2{,}8976x - 5{,}4119}{-0{,}0009x^2 - 0.099x + 196.78}$$

After calculations, we obtain the dependence S_{sn5} (cm^2) given in Figure 5.

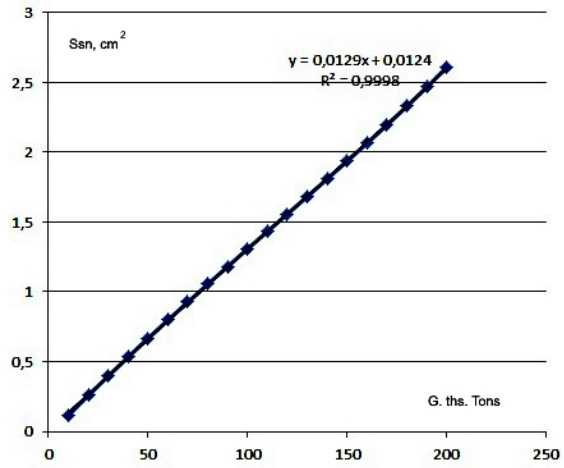

Fig. 5. Growth of the conditional worn-out area S_{sn} (cm^2), lining depending on the amount of ore processed G, ths. tons.

As you can see, the expansion of the conditional worn-out area of the S_{sn} lining is linear and directly proportional to the volume of crushed ore.

4.5 Fifth stage of research

On a pilot sample mill MMS–90–30 also conducted researches of wear of elements of lining, made of cast iron RF–4. To characterize the wear of the lining, mass deterioration of all its elements was determined (Table 1).

From the analysis of the data obtained, it can be seen that the lifters made of cast iron RF–4, for 5 months of

work, were worn only 15 mm and were suitable for further operation. During this time, serial lifters from the 110G13L alloy were worn by an average of 55 mm in height and were partially replaced by new ones. From the SS alloy were manufactured and tested lifts 2 and 3. Lifts 3 for wear resistance were the same as serial lifts from steel 110G13L. The durability of lifters 2 from the SS alloy was significantly higher: after 5 months of operation, their average height was 110 mm, while the height of serial lifters decreased to 80 mm.

Table 1. Results of research of wear of lining of mill MMS-90-30.

Lining	Number	Total mass, kg	Mass of worn part, kg	Relative wear, mass, %	Processing of ore, tons	Specific costs of mass lining, kg
Lining of the loading end wall	98	37159	3255	8,76	379,3	8,587
Load lifts	84	14504	3460	23,85	379,3	9,122
Armor shell ring	56	38080	1120	2,94	379,3	2,953
Lifts collars	56	22960	4200	18,29	379,3	11,073
Grates	70	23157	7486	32,27	379,3	19,736
Lattice mounting lifts	70	15582	1070	6,86	379,3	2,820
Lining under grates	70	63084	9364	14,84	379,3	24,687
Complete lining kit	504	214526	29955	13,96	379,3	78,978

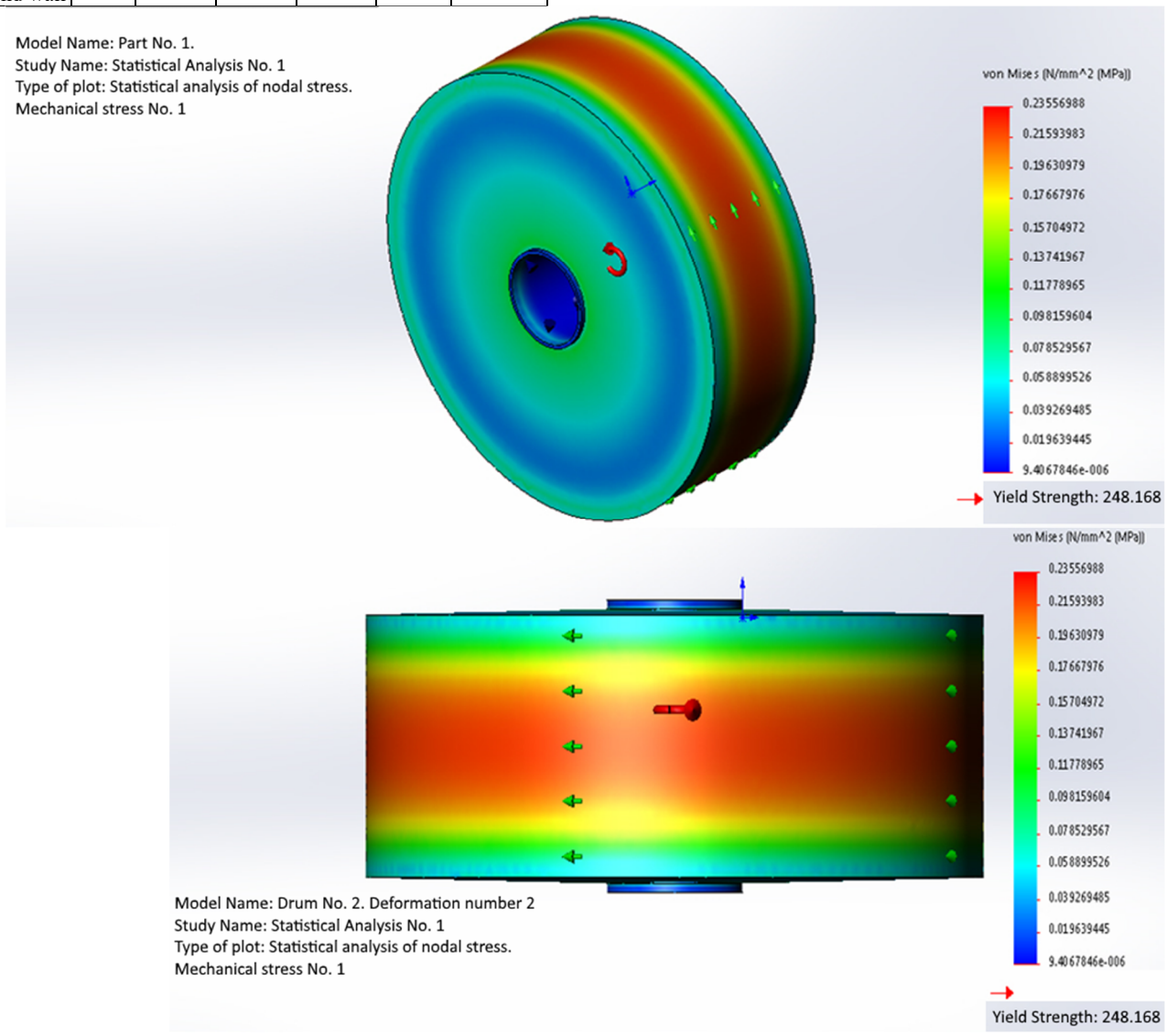

Fig. 6. Parametric field of strength of the drum mill self-grinding at idling speed. Trapezoidal drum wall with bases: upper – 70 mm, bottom – 200 mm: a – isometric projection of the drum; b–the drum's side (profile).

The nature of the wear of elevator lifters in height is the same as the elevators of the mill MMS–70–23.

Experience has shown that lining, made of wear-resistant cast iron RF–4, is more durable than lining steel 110G13L. Lifts, made of cast iron RF–4, especially lift loaders, are more fragile and after 3–4 months. Operation is broken up by large pieces of ore, which is fed into a mill. Broken and torn elevators during rotation of the drum break other elements of the lining, which leads to the need for premature stopping of the mill for re–fusion. The following lines of service of separate groups of lining of mills MMS–90–30 are established: the armor of the loading end wall – 5 – 7 months; load lifters – up to 5; armor and lifts of luggage – up to 4; lattices – up to 4; sublattice lining – 7–8 months. Thus, the service life of individual elements of the lining of mills MMC–90–30 is relatively low and, most importantly, is unplanned, which makes it difficult to establish optimal inter–repair periods. In addition, the lack of service life of individual elements of the lining leads to the fact that when replacing a number of extremely worn items must be replaced and those elements whose wear is insignificant and they could work for a long period.

A significant disadvantage of the lining of mills MMC–90–30, which negatively affects the term of their service, there is also low reliability of nodes fixing elevators and lattices. As a result, there were cases of a breakdown of relatively few worn elevators and the loss of grate, which as a result of the dynamic impact in the process of the mill on other elements of lining removed them from the system. Therefore, in order to increase the efficiency, wear resistance and durability of the lining of serial mills MMS–90–30, it is necessary to apply high–strength materials and constructive improvement of all elements of lining, especially the nodes of fastening of elevators and lattices.

4.6 The sixth phase of the research

At this stage, using the SolidWorks software simulation statics module, mechanical stresses in the area of the shell were investigated. The obtained models in the idle mode mill mill itself (Figure 6) show an abnormally high mechanical tension in the vicinity of the vertical axis of the drum. For the loaded (nominal) operating mode of the mill itself, the grinding by the rule of superposition should be expected to increase the voltage in this zone – as the voltage at idle and the load factor will be added.

Reception of the epic of the stress of the elements of the drum mill self-crushing at different loads of the mill in the ore is an independent task and is planned by us in the subsequent studies.

At the same time, it should be emphasized the convergence of the data of simulation of mechanical stresses in the zone of the shell (Figure 6) and the real one, – experimentally established, – pictures of wear of the lining of mill MMS–90–30A (Figure 7).

5 Conclusions

1. According to the location and nature of the wear processes, inserts-lifts appropriate to be divided into the following groups: I. Lifts, located on the end wall of the load; II Lifts, located on the shell; III Lifts, located on the end wall on the side of unloading. Monitoring of wear of lifters of semi-autogenous grinding mills was executed in conditions of Ingulets GOK within 1 year.

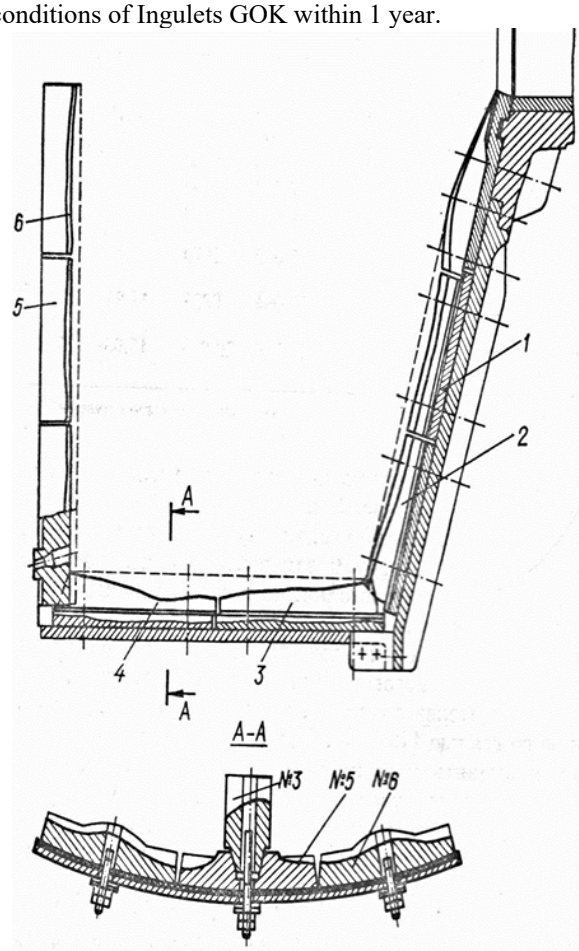

Fig. 7. The demolition of elements of lining of mills MMS–90–30A was experimentally established. 1,2 – lining and lifters of the loading end wall; 3, 4 – lining and lifts of the drum shell; 5, 6 – gratings and lifters of the zone of unloading; No. 3, 5, 6 – the numbers of lining and lifts of the lining.

2. On the basis of the experimental data regression received in the Microsoft Office Excel, a set of mathematical models of lifters' wear was obtained in terms of height, weight, volume and worn-out area.
3. From the analysis of the obtained data it is seen that the lifters made of cast iron RF–4, for 5 months of work, were worn only 15 mm and were suitable for further operation; During this time, serial lifters from the 110G13L alloy were worn by an average of 55 mm in height and were partially replaced by new ones. Thus, the selection of lift materials can be reduced by 3 times the inter–repair period (replacement of worn lifts).
4. Comparison of the real picture of wear of elevators and simulated using the simulation statics module SolidWorks stresses shows the convergence of the arrangement of zones of maximum stresses and maximum wear of the lining.

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Development of intelligent energy systems: the concept of smart grids in Uzbekistan

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Abstract. In the process of energy reform, liberalization and deregulation of the electricity market, a number of features have been identified that are related to the fact that in the conditions of market relations, the economic benefit and the price of electricity for consumers become a priority. There is certain isolation of networks and power lines from generation facilities; attention is lost to such an important problem as the reliability and safety of power supply. In this situation, the load on the power elements of the electric network increases, there is a need to create appropriate reserves of generating capacities, to increase the throughput of electric networks. All this involves increasing the role of system operators and improving supervisory control systems. The strategic goal of this study was to analyze the development of the electric power complex by the creation of smart grid systems as a platform for market, managerial and technological innovations that provide a transition to a new level of development of the electric power industry in Uzbekistan.

1 Introduction

In the last decade, the Smart Grid concept, which means an intelligent power system, has been actively discussed and developed abroad. In the USA and the European Union, it is considered as a technological concept of the electric power industry of the future [1-3] and it is, in fact, the state policy for the technological development of the electric power industry of the future.

There are various points of view on the concept of intelligent networks [4]. This explains the fact that, despite the relative similarity of the main factors in the development of intelligent networks in different parts of the world, the priorities are different. For example, in the EU, the priorities are the problems of integrating renewable energy sources, energy efficiency, as well as integrating the EU markets within the framework of a carbon-free economy, while for the United States, such problems as disruption of energy supply, situations of peak power consumption and aging of production facilities are priority. In China, the rapid development of the energy system, the need to unite large wind farms in the northern regions and create links between different provinces is the most urgent priorities.

The most general and technically complete definition of the concept of Smart Grid was formulated by scientists from the Institute of Electrotechnic and Electronic Engineers (IEEE). So, according to their definition,

Smart Grid is a fully integrated self-regulating and self-renewing electric power system with a network topology that includes all generation sources, trunk and distribution networks and all types of electricity consumers, which are controlled using a single network of information and control devices and real-time systems. In fact, an intelligent electric network unites not one, but two networks – an electric and information-control network, which closely interact with each other and function simultaneously. Moreover, the management and control of each device of the electric network are carried out using the necessary "intelligent" devices, combined into a single information-control network.

Despite the existence of a number of definitions of the concept of intelligent energy systems, they can be generalized by defining an intelligent energy system as a combination of energy infrastructure and embedded / distributed information and communication technologies (software, automation, information processing). The combination of two infrastructures provides the necessary "intelligence". This intelligence can be represented at different levels of the network (generation, network software, consumption, monitoring and control). Three basic principles of Smart Grid can be distinguished: security, standardization, integration.

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The reasons for the transition to Smart Grid are as follows: reduced predictability of demand behavior; the emergence of consumer generating ability and the need to return electricity back to the network; low energy efficiency and environmental friendliness of a grid built on analogous principles and technologies; digitalization of management of individual network elements and the risk of reducing their ability to mutual integration; the problem of the stability of hierarchical energy systems.

The main competitive advantages of smart grid technologies are: local measurement and monitoring; remote measurements and control; multi-information measurements and monitoring; controlled measurements and monitoring; general improvement in the quality of electric energy; low operating costs; minimization of expensive visual inspections of the system; automatic recording of time and operating parameters of specific equipment for timely preventive repairs; reduction of electric energy losses, improvement of environmental conditions, minimization of light and noise pollution; the best level of reliability and security; quick response to changes in external conditions; quick and easy access to the system database. The development of Smart Grid technologies also means a fundamental reorganization of the market for electric energy services [1, 2, 5-8].

Already today, the world has developed the understanding that a quick transition to the ideal Smart Grid model is impossible. In this regard, three generations of Smart Grid have been singled out, which make it possible to gradually move towards the target model: Smart Grid 1.0 – state of the electric power infrastructure, in which individual devices and system objects can be connected to the network without using common digital standards; Smart Grid 2.0 – the state of the electricity infrastructure, in which the connection of any system nodes is possible only if it is switched to a single IP protocol and included in a single integrated IP network; Smart Grid 3.0 is a flexible energy system that is based on the principles of decentralized management and equal rights for consumers and suppliers.

Hence, this study aims to present possible list of stages of the concept for creating smart grids in Uzbekistan by analysing the development of the electric power complex via creation of smart grid systems as a platform for market, managerial and technological innovations that provide a transition to a new level of development of the electric power industry.

2 Construction features and components of intelligent control systems

Today, the complexity of managing the electric power system is so high that fully centralized management becomes ineffective due to the presence of huge flows of information, when too much time is spent on transferring it to the center and making decisions [4, 6, 8, 9, 10, 11-13]. Control systems include a number of subsystems with different functional characteristics and interacting with various specialists, remote from each other. Therefore, some elements of organizational management should be transferred from the center to the periphery with a clear delineation of rights and information access. The management system of the UES of the upper level should be a coordinating information management system that operates on the basis of appropriate standardized protocols and interaction interfaces.

The construction of a traditional control system of the unified electric power system (UEPS) is carried out according to the hierarchical principle with allocation of zones of responsibility for managing a certain level of the hierarchy [11-13].

A calculated union of groups of nodes that have “strong” connections with each other into one “equivalent” node with a total generation and consumption in this node takes place at the highest levels of the control hierarchy, and control is carried out by “weak” connections between these nodes for the output of parameters characterizing their work outside of normal mode. For each of the control levels, the processes of normal functioning are determined when disturbances in control node do not lead to an imbalance between consumption and production, and also do not cause disturbances in the connections operation between the nodes. In this case, the control carries out the process of transition from one stationary state to another, optimizing the current processes (modes) of the power system.

Power system objects are owned by various organizational structures with various commercial interests; therefore, when organizing the management process of such a complex object, it is necessary to take into account the market nature of relations between them, solving problems of resolving a conflict of interest. Therefore, commercial agents also function at each level. The infrastructural limitations associated with the insufficient bandwidth of many communications dictate the need to divide the common electric power system into electric power segments of UEPS.

Reliability issues in modern power grids are becoming increasingly problematic. The factors that determine the occurrence of these problems [9-13]:

- increased network congestion due to uncertainty, diversity and distribution of energy supply, taking into account environmental concerns and sustainable development; real-time electricity flows can significantly differ from those imposed during design or on-line analysis;
- increase in the number of powerful power lines over long distances contributes to the growth of instability and reduce the margin of safety; this phenomenon is reinforced by energy markets;
- the network is managed from one “end” from various locations and often taking into account the “lack” of investments and the restriction of land allocation; increase in energy consumption and peak demand creating a “conflict” with limited transmission capabilities; infrastructure aging; maximization of asset utilization thanks to modern technologies for monitoring, analysis and regulation;
- a consolidation of operator companies contributes to an increase in “area (covered by networks)” with more complex problems and requires more accurate

information and shorter time to make decisions; this problem is exacerbated by a lack of qualified personnel due to aging staff.

Under ideal conditions of demand management, energy storage and electric vehicles will be closely coordinated with other resources, so the total energy consumption will be almost uniform. This suggests that the network will be operated according to the conditions of near-peak load for almost the entire time. First, a decrease in total power consumption led to an increase in reliability by reducing the peak. However, over time, in the face of an increasing load, opportunities for optimal transmission and use of distribution assets, total energy consumption will approach the ultimate capabilities of the power system. Thus, a system will be close to the "limit" much more often, which leads to a greater likelihood of failures and exacerbation of reliability problems, respectively, the need for intelligent networks will increase.

The implementation of the Smart Grid concept provisions for a construction of an intelligent electric power system (IEPS) requires ensuring reliability through the use of modern information and communication technologies (ICT) in order to create an infrastructure that would ensure the coordination of monitoring and regulation throughout the network. Such an IT infrastructure should ensure trouble-free and almost instant two-way interaction between all devices - from individual loads to network control centers, including all basic equipment at the transmission and distribution level. This requires the processing of a significant amount of data for analysis and automation, which is associated with a high-performance infrastructure capable of delivering highly intelligent local pre-second reviews coordinated with higher-level global analysis to prevent or contain rapidly occurring adverse events. The centralized system was too slow for this kind of task. Distributed architecture allows you to create a high-performance infrastructure with a local intelligent pre-second response using modern technologies, which is based on the following:

- advanced telemetry: using PMU technologies for faster, time-stamped, clearer, second-second scans to provide up-to-date information about the network status;
- devices for faster regulation: using powerful electronics for faster automatic regulation, voltage and power flow control at the level of transmission and distribution;
- more robust regulation: actively adaptive regulation of protection and control for a wide area of monitoring and regulation, including an international division of UEPS;
- embedded smart devices: in order to prepare for the use of adaptive intelligent control: diagnosing equipment level failures and poor-quality data identification; operations within the limits are remotely reported by the system operator or regulatory centers; "Intelligent" RAS / SPS etc .; automatic equipment recovery; automatic local regulation; integrated and secure communication systems: distributed and comprehensive communications based on open standards, which allow creating flexible network configurability for the purpose of trouble-free monitoring, automation, two-way communications between all operators and agents;
- use of computer capabilities: trouble-free and secure systems for reliable analysis in order to support the decisions of the operator and stand-alone functional agents controlled by a geographically and time-coordinated hierarchy in IT infrastructure of the network;
- Internet technologies: internet protocols to simplify the exchange of data, a regulatory process and cyber security for implementation of a distributed architecture based on standards with open interfaces.

The hierarchy of control levels in an intelligent electric power system reveals the concept of "smart grids" as a combination of energy and information and communication technologies, representing the possibility of more efficient management of UEPS through the exchange and management of technological and marketing information.

3 Intelligent forecasting in IEPS

The development data of recent years is focused on the development of predictive approaches based on algorithms and methods of artificial intelligence: neural network technologies, expert systems, machine learning models, fuzzy calculations, etc.

Despite the advantages of intelligent forecasting algorithms, indicated in a number of articles of recent years, many researchers believe that the issue of high efficiency, for example, artificial neural networks (ANNs) or fuzzy systems, in solving the problem of predicting aircraft is still open. An intelligent solution to the above cases is the use of hybrid approaches and models, when the combination of various intelligent and traditional models allows you to get the most effective solutions, first of all, guaranteed forecast accuracy. The following combinations can be attributed to promising hybrid models at this stage: fuzzy systems and ANN, expert systems and ANN, Hilbert-Hung transformations with ANN models, etc.

The concept of intelligent monitoring includes the following actions [12-15]: collecting data that is fed to data pre-processing systems that determine the most important and critical data that affect the development of the regime; classification (clustering) of EEC states - the purpose of this procedure is to determine how dangerous a particular state of the system is; interpretation of the resulting clusters (states) so that an operator can develop and implement preventive measures.

For operational dispatching control of the International Electrotechnical Commission (IEC) modes, new means of measuring the regime's parameters of power systems (Phasor Measurement Units, digital measuring instruments) and controlling them (FACTS, energy storage, etc.) should be used, which radically increase the observability and controllability of power systems, modern means of communication, new information technologies and methods of artificial intelligence, high-performance computer tools. They fundamentally change the processes of collecting, processing, transmitting, presenting (visualizing) and using information, and on a new basis, they can

significantly increase the efficiency of operational dispatch control of modes. The development of operational dispatch control methods is associated with IEPS improving information support, automating the preparation of operational solution options, automating management, increasing a share of automatic control in the tasks of regulating and limiting mode parameters, automating the calculation of optimal modes, implementing them, etc., while maintaining control from operational dispatching staff in the required amount [16-19].

Today, the problems of constructing intelligent distribution networks relate mainly to their development on the basis of modern telemechanics and telecontrol facilities, as well as data transmission channels. However, the basis for the optimal functioning of the intelligent network should be provided by control algorithms and software.

The source of information for the operational control system can be the telemechanics devices of the main step-down substations. Distribution network power centres usually have the following telemetry: tire voltage, total active and reactive load, and current load of feeders. If there are reclosers in some feeder branches, the one can additionally obtain information about the current of the site and the voltage of the node at a place of its installation. The recloser at the point of opening the network allows you to control the voltage of the nodes, the difference of which allows evaluating the current efficiency of installed breaks. The observed mode parameters with a fixed operational scheme allow us to estimate the magnitude of nodal loads, using, in addition to telemetry, statistics regarding the loading of transformer points.

Based on the results of an operational assessment of the state of each feeder, it is possible to search for optimal control actions using well-known methods for analysing the modes of electric networks. Today, these methods, as a rule, are developed on the basis of an iterative solution of systems of nodal nonlinear equations and are focused on calculating the modes of multiple closed networks. Unlike the backbones in distribution networks, the design diagram is open in accordance with the operational position of the working openings, the graph of which is represented by a set of branches forming a tree and chords corresponding to disconnected branches.

One of the control tasks in distribution networks is to find the optimal operational circuit and mode parameters when changing loads, supply voltage, etc. Optimization criteria for the hourly step of the graph are power loss, quality and reliability. Often, they are contradictory; therefore, a search for the optimal solution is carried out in the Pareto region. However, such multicriteria problems can be reduced to one criterion. Reliability can be taken into account as a restriction on the acceptable parameters of the mode and fixing some openings in the network to provide power to responsible consumers from two sources.

The quality criterion can be estimated by the minimum release of energy at voltages that go beyond the permissible region, which can be individual for each characteristic consumer.

Independent parameters for optimizing the parameters may include: voltage level in the power centre, which is determined by the number of a soldering regulation under voltage, a reactive power of small generation plants and the position of the cuts on the full network graph.

4 The development of smart grids concept in Uzbekistan

World experience shows that smart grids can be built in several stages. The first stage is the development of the concept of building a smart grid. The second and third stages can be implemented in parallel: work on the creation of interfaces that can connect the modernized facilities of the main electric grid economy with generation and consumers which is simultaneously carried out with the development of pilot projects, within the framework of which technologies are being developed for the creation of intelligent power system (IPS). Fig. 1 highlights the basic concept for smart grid development in Uzbekistan.

Possible list of stages of the concept for creating smart grids in Uzbekistan:

1. New solutions and technologies (breakthrough and improving): new types of electrical equipment, including new systems for monitoring the condition of equipment, self-recovering, relay protection and emergency automation, energy metering systems.

2. Information interaction and control systems: the creation of information infrastructure, its integration with the electric grid, information support and optimization systems for managing all processes in the electric network.

3. Regulatory aspects: a new range of services that is provided by electric power industry entities; normative distribution of roles in the interaction of electric power industry entities in the new conditions, including the development of network rules.

4. Creation and implementation of pilot projects (energy clusters): integration of electric grid and information infrastructure, integration of all types of generation, energy storage systems; creation of an all-regime management system with full-scale information support, optimization management systems; selection of zones for the implementation of pilot projects, assessment of technical, economic, environmental and social effects.

5. Duplication of results, cluster consolidation, creation of intelligent energy systems in Uzbekistan, replication of the successful results of pilot projects, integration of energy clusters into a single electric power system.

Expected results from the implementation of Smart Grid:

1) the most efficient use of energy resources;
2) removing the network economy from the crisis by replacing obsolete equipment;
3) reduction of electricity losses, its significant savings;

4) reduction of emergency shutdown time; increasing the efficiency of loading electrical equipment;
5) increase in volumes of electricity transit by 15–20% without the construction of new network facilities;
6) reduction in energy production costs;
7) reduction in the cost of utilities;
8) the use of alternative energy sources;
9) reduction of the environmental impact of energy facilities (reduction of CO2 emissions in the atmosphere);
10) providing a model of two-way communication with the consumer;
11) identification of a theft of electricity, equipment damage and their timely elimination.

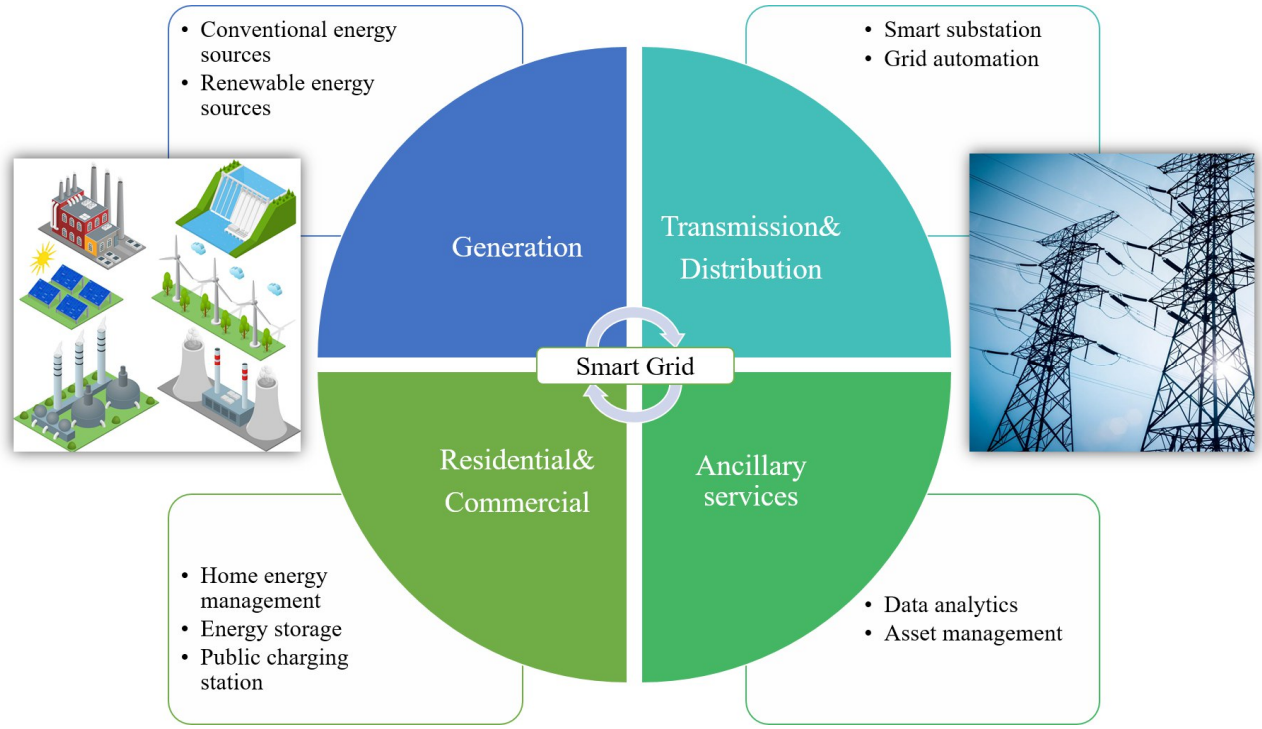

Fig. 1. The basic concept of smart grid development in Uzbekistan

Advancement of the Smart Grid concept requires a change in many elements of the power system. Their success depends not only on installing new meters and improving the efficiency of electricity supply but also long-term measures are needed, such as the development of power electronics and devices based on it, primarily various kinds of network-controlled devices (flexible AC transmission systems – FACTS) to increase line throughput and ensure stable operation of the power system under various disturbances, widespread development of distributed generation and renewable energy sources. It should be borne in mind that various technologies of the smart energy system are being introduced on the market and at different speeds.

Another obstacle to the comprehensive implementation of the concept of an intelligent energy system is the difficulty of reconfiguring the relationships between electric power entities, since the implementation of Smart Grid concerns all direct participants (individuals and legal entities of any form of ownership) of the processes of production, transmission, distribution, consumption, purchase and sale of electric energy.

Accordingly, the scope of such a project is commensurate with the scale of creation of a new electric power system, including the depth of elaboration and detailing for each individual power receiver.

The introduction of innovative technologies is connected with the solution of two critical issues that will allow a fresh look at the relationship between the consumer and the energy company: providing the consumer with two-way control technology that can help manage the declared peak power; an implementation of dynamic pricing in the retail electric energy market, stimulating consumers to change their usual load schedules.

5 Conclusions

Thus,
- the tasks of the electric power systems development were formulated,
- the main directions of the intelligent electric power systems development were evaluated,
- the necessary technological basis was described,
- the requirements for the areas of use of IEPS were sufficiently detailed,
- the construction features and the components of intelligent control systems were presented.

The introduction of Smart Grid leads to a change in the energy system's functioning technologies (direct consumer load management, dispatch modelling, real-time distributed system analysis tools, demand response analysis, system emergency recovery support, etc.), to a

change in the energy management system (new architecture program security, management system), to the formation and growth of new markets. It is possible that smart grids will not only contribute to the modernization of the Uzbekistan energy system, but will also help to create a new electrical base for the production of equipment.

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Analysis of consumption and ensuring energy resources of the Dnipropetrovsk Region

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Abstract. The issue of energy-saving and energy efficiency is actual at the present-day development of Ukraine's economy. The imperfective system of energy ensuring as the result of inefficient energy resources utilization is a characteristic feature of the state. The analysis of ensuring energy resources applied to Dnipropetrovsk Region as one of the leading industrial regions of the country is presented in the article. The availability of reserves and production of fuel resources was analyzed in it. Distinctive features of energy resources consumption with the aim of assessment general and partial indexes of energy ensuring and fuel power-intensity of the region's economic complex are highlighted in the work. The tendencies and perspectives of energy consumption development of the Dnipropetrovsk Region were analyzed herewith.

Introduction

The problems of ensuring any country with its own fuel-energy resources are considered as the most acute and urgent ones because they refer to a country's energy safety. Under conditions of formation and realization of energy ensuring strategy and optimizing energy consumption resources, which are the basis of a territory economy development, the issue of sufficient volume of fuel energy resources availability for renewable processes in industries of the national economy as well as ensuring energy, economical and correspondently national security arises acutely [1].

Fuel-energy resources as any other resources are located very much unevenly on the territory of the country. So there arises the necessity of exploring deposits, their extraction, beneficiation, processing and transportation which stipulates the development of mining industry. Energy safety, in its turn, demands the assessment of resource and energy potential of the territory, includes the control over energy resources, energy-saving and energy efficiency.

Crisis periods in economy, fuel price fluctuations and the present-day environmental challenges demand a transition from increasing output of traditional to renewable energy resources. Monitoring the resource base of fuel energy raw materials remains actual, in particular, the regional analysis of characteristic features of consumption and ensuring fuel energy raw materials by individual regions of the country.

The issues of the country's (a region's, a territory's) energy safety were comprehensively researched in the works of A. Yerina [22], O. Kolodiazhna [22], V. Lir [17], V. Mykhailov [11], M. Mazur [3] et al. Ensuring mineral energy resources and rational nature management were considered in the works of M. Korzhniev [23], Ye. Yakovliev [23], M. Syvyi [20] and others. They concerned the analysis of the present-day status of Ukraine's mineral-and-raw material base, solving the problems of development and restructuring mineral raw deposits, improvement of the system of state management for mineral resources use. Much attention is paid to the problems connected with the usage of non-traditional sources of hydrocarbons. S. Vakarchuk [9], M. Syvyi [21], N. Khomenko [10] carried out the study of methane use and extraction possibilities at coal deposits, shale gas – by S. Vakarchuk, O. Zeikan and others [9]. Hence, the problem of formation of stable energy ensuring remains actual and demands further researching.

The purpose of the research is the analysis of energy resources consumption by the Dnepropetrovsk Region and providing its needs for fuel-and-energy raw materials; assessment of the role and place in the structure of consumption energy resources of own extraction, as well as the present status of energy extracting industry; revealing the problems and perspectives of its development.

1 Energy resources consumption in the Dnepropetrovsk Region

The Dnipropetrovsk Region is one of the major industrially developed territories of Ukraine, the development of which is grounded on mineral resources extraction and processing, steel making, mechanical engineering, chemical industry that have high indexes of power-consumption. The Region's share in the national industrial production made up 22.5% in 2018 and the Region ranks the first place in Ukraine by this index.

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The Region is also one of the biggest energy resources consumers (Fig. 1) [2].

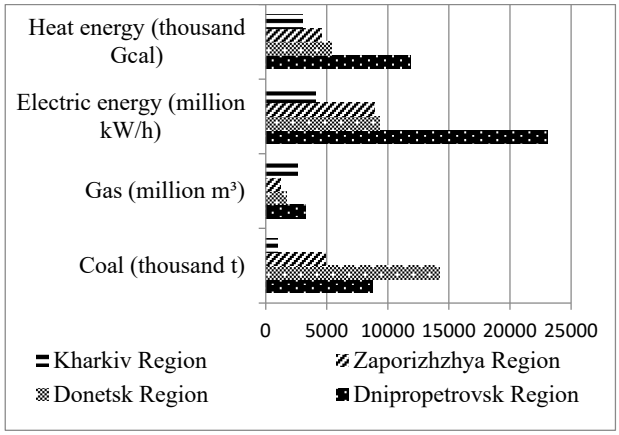

Fig. 1. The place of the Dnipropetrovsk Region among Ukraine's regions in relation to various energy sources consumption in 2018 (on the basis of Dniprostat data).

In the opinion of M. Mazur it is typical for the territory to use fuel energy resources (FER) in stages: ensuring formation of the resource base; fuel energy resources extraction; energy generating and transformation; fuel and energy transportation; energy and fuel consumption. Each stage is characterized by indexes of power-consumption, usefulness of the resources, fuel energy resources losses.

Reducing in losses at each stage will allow to involve energy-saving potential, and the use of unconventional sources of energy will allow replacement potential of nonrenewable resources by renewable ones and minimize the negative environmental impact [3].

By the year 2018 in the structure of Ukraine's energy resources consumption the volumes of coal prevailed (39.2%) that of coke and semi-coke from coal; gas coke (28.6%) and natural gas (13.8%) [4]. Fig. 2 illustrates energy resources consumption from 2011 up to 2018 period. The tendency of decreasing natural gas consumption and increasing coal and coke usage was observed through this period.

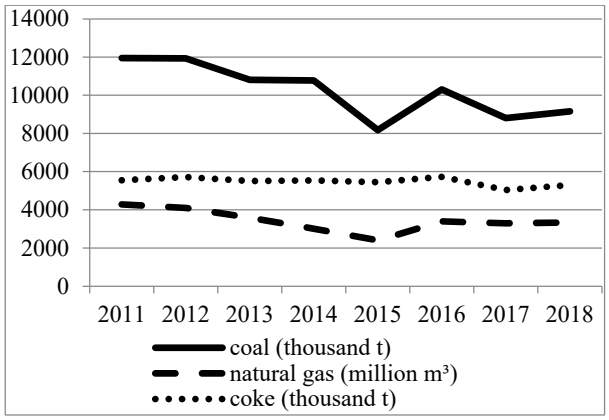

Fig. 2. The dynamics of energy resources consumption in the Dnipropetrovsk Region during the period of 2011–2018 [4].

The generalized index characterizing a region's economic growth at the regional level is Gross Regional Product (GRP), which can be applied to calculation a production's fuel energy capacity. Economical indexes of the Region during the years 2014–2015 had the tendency of decreasing due to the economic crisis. General drop in the Region's economy at that period amounted almost to 12.5%. Since 2016 economic situation in the Region has stabilized and the rates of growth have been gradually recovered (Table 1). The coefficient of fuel energy capacity index calculated by the authors is a ratio of GRP to the fuel consumed. It illustrates general efficiency of fuel consumption in the Dnipropetrovsk Region on the basis of GRP ratio per one hryvna (UAH). As seen from Table 1, fuel consumption in the Region has a stable tendency to decrease, though the level of fuel energy capacity remains rather high. It is important for the Region's steady development that economic growth would be synchronized with decreasing of GRP fuel energy capacity.

Table 1. The dynamics of general level of fuel energy capacity the Dnipropetrovsk Region during 2010–2017 [GRP] [5].

Years	Fuel consumed (thousand ton of conditional fuel)	GRP in actual prices (million UAH)	Fuel energy capacity coefficient (kg, conditional fuel / UAH)
2010	23074,6	116136	0,198
2011	22838,9	140020	0,163
2012	21980,3	147970	0,148
2013	21199,1	152905	0,138
2014	18159,8	176540	0,109
2015	21200,0	215206	0,098
2016	19203,0	244478	0,078
2017	19900,0	313830	0,063

In the structure of the fuel consumed according to the types of economic activities by the main consumers there are enterprises of steel production, their share made up 63.1% of total volume of consumption. So, the measures for energy-saving in steel production are of top priority.

There are over 500 industrial enterprises on the territory of the Region. From the territorial point of view, the main fuel consumers are three cities: Kryvyi Rih (46%), Dnipro (19%) and Kam'yanske (18.3%). Unit weight of coke consumption by Kryvyi Rih enterprises makes up 65% of total consumption, natural gas – 47.4%, coke – 30.4% [6].

Thermal power stations are significant sectoral consumers of energy resources in the Region: Kryvyi Rih TPS (2892 MW output) and Prydniprovsk TPS (1765 MW output) which are included into the united power system of Ukraine and they are coal-based operating [6].

The Dnipropetrovsk Region is one of the most urbanized regions in Ukraine. 20 cities, 46 towns and 1435 villages are located on the Region's territory. The share of city population in the Region makes 83.61% as per average index of 69.23% in Ukraine. That is why the major Region's gas consumers are the population, industry and government-financed organizations (Fig. 3). The statistics data analysis of natural gas consumption by the population in 2018 showed that volumes of

realization dropped by 20% as compared to the previous year due to gas price changes, and the use of firewood for heating raised almost by 6 times.

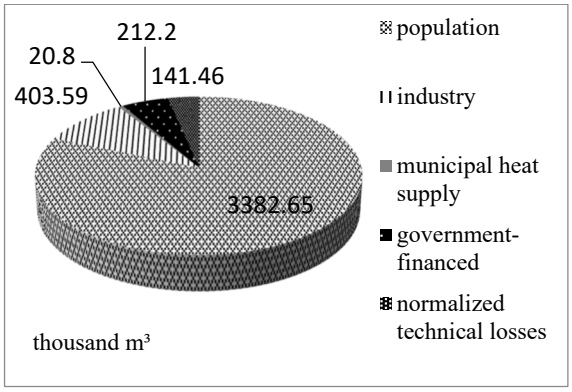

Fig. 3. Natural gas consumption by consumer categories in the Dnipropetrovsk Region, thousand m^3 (2018) [6]

To make assessment of the Dnipropetrovsk Region ensuring with its own fuel energy resources (hydrocarbons, hard and brown coals) it is necessary to analyze the present day status of their deposits, demand, the ways of technical re-equipment and restricting the mining industry.

2 Fuel mineral resources extraction in the Dnipropetrovsk Region

The deposits of fuel energy raw materials in the Dnipropetrovsk Region are exploited for a long time (gas, oil, hard coal) hence, some of them (brown coal) remain unclaimed or need further researching (unconventional types).

2.1 Natural gas and oil

15 hydrocarbon deposits have been registered [7] in the Dnipropetrovsk Region, the major part of which are integrated ones, namely 4 gas fields, 5 gas-condensate fields, 7 oil-and-gas-condensate fields, out of which 12 are exploited and 3 are being explored.

Oil and gas fields are located in the north-east of the Dnipropetrovsk Region and belong to the Dnipro-Donetsk oil- and gas-bearing region (DDOGR). Referring to tectonic aspect DDOGR is located within the Dnipro-Donetsk depression (DDD). The depression was formed with thick rock sediments aging from Middle Devon to Neozoic.

Hydrocarbon deposits on the territory of the Dnipropetrovsk Region belong to Rudenkivsko-Proletarskyi oil-gas-bearing region the main part of which is located within the Poltava Region. The region is attached to the south-east side-board of the DDD and presented by hydrocarbon deposits in sediments of the Middle, Lower Carbon and Devon. In the boundaries of the Dnipropetrovsk Region there is Mykhailivsko-Leventsivska zone of oil-gas accumulation.

Many of the explored deposits belong to the small categories having less than 5 billion m^3 of gas reserves. Separate deposits of medium size (*Proletarske, Ul'yanivske*) are substantially exhausted and do not make any difference from others (Table 2). The deposits' free gas is high-caloric (30-40 thousand kJ), being mainly sulfur-free, with minor nitrogen and carbon-oxide gas content. Gas consistency in relation to the air varies from 0.556 to 1.1. The current state of fixed condensate in gas is changing from 1 to 2 265 g/m^3. An average ethane, propane, butanes content in free gas makes correspondently: 5,58; 2,06; 0,74%; helium – 0.07% [7].

Gas reserves make about 1.5%, oil reserves 0.9% and gas condensate 2% of the national ones (Table 2).

Table 2. Distribution of reserves (by 01.01.2019) and hydrocarbon extraction (2017) among the deposits in the Dnipropetrovsk Region (on the basis of Geoinform data).

Deposit	Oil (thousand t)		Gas (million m^3)		Gas condensate (thousand t)	
	Extracting balance reserves	Output	Extracting balance reserves	Output	Extracting balance reserves	Output
Mykhailivske (OGCD)	–	–	332	6	–	–
Pereschepynske (GCD)	8	–	2131	44	119	1
Bagatoiske (GCD)	–	–	1726	69	165	2
Golubivske(OGCD)	526	3	412	–	24	–
Leventsivske (GCD)	–	–	307	25	–	–
Yuriiyvske (OGCD)	18	1	164	2	5	–
Lychkivske (OGCD)	73	2	64	6	4	1
Kremenivske (OGCD)	367	5	1828	39	83	–
East-Novoselivske (GCD)	28	–	1313	48	200	1
Novoselivske (GCD)	1	–	315	2	–	–
Vynogradivske (GCD)	–	–	300	6	1	–
Proletarske (GCD)	1355	–	1521	105	43	1
Ul'yanivske	23	–	1955	199	48	2
Musiyenkivske	–	–	332	–	–	–
Total	**2399**	**11**	**12700**	**551**	**692**	**8**

Three projects (two deposits and one area) Ryaskivske, Musiyenkivske, East-Golubivsk are prospective for oil and gas extraction after carrying out a complete volume of geologic exploration works. But a detailed geologic exploration of the underground resources and provision of the necessary facilities for the deposits demand considerable investments [7].

The following companies such as Joint Stock Company "Ukrgasvydobuvannya" and PJSC "Ukrnafta" are dealing with oil, gas and gas condensate extraction on the territory of the Region.

As seen from the Fig. 4, there exists a considerable unbalance in the Region between the levels of consumption and supplying its own energy resources. Energy safety demands searching for efficient decisions

related to regulation of available resources consumption.

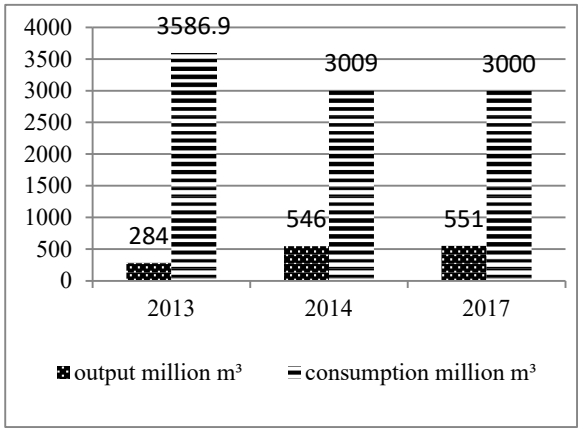

Fig.4. The dynamics of gas extraction and consumption in the Dnipropetrovsk Region in 2013–2017 [4].

The tendency in drop of the level of natural gas consumption and its import in Ukraine has been observed since 2016, which is undoubtedly a positive factor. At the same time, by the current decreased level of consumption – over 30 billion m^3/year – the country is not able to provide itself with its own resources (20 billion m^3/year). The Government's Decree "On Approval the Concept of Gas Extracting Industry Development in Ukraine" dated on December 28, 2016 No.1079 set the target: to produce 27 billion m^3 in 2020, though it is not realistic due to the lack of financial means for substantial expanding geologic exploration works, introducing up-to-date methods of intensifying exploration, maintenance and development of gas industry.

At present, there are only solitary instances of applying up-to-date methods of intensifying exploration. Beginning from September 2016 JSC "Ukrgasvydobuvannya" got additional 261 million cubic meters of gas in the Ul'yanivske field at the cost of carrying out works for beds (layers) intensification by the method of hydraulic breaking (HB). Hydraulic breaking (HB) works were performed by the Belorussian state-owned company "Belorusneft".

2.2 Brown coal

Brown coal fields are concentrated in Verhnyodniprovsk, Synel'nykove and Petrykivka districts of the Dnipropetrovsk Region and attached to the Dniprovsk brown coal field of the West Donbas. The brown coal deposits belong to the Paleozoic (Lower, Middle Carbon) and Neozoic ages (palaeogene).

The Paleozoic deposits are spread out in Petrykivka geologic-industrial district of the West Donbas and attached mainly to Samara coal-bearing, partially to Mezhive formation of Lower and Mospine formation of Middle Carbon. Highly metamorphized brown coal of Petrykivka deposit with total reserves of 0.3 billion ton belongs mainly to so-called saline coals and has the increased content of water-soluble natrium salts, for this reason its exploration has been stopped.

Coal-bearing Palaeogene (Neozoic) age deposits are attached to multiple depressions on the surface of Ukrainian shield. Paramount volume of balance reserves of coal industrial categories is concentrated in the Dnipropetrovsk Region – not less than 1 billion ton, or 55.6% of the total reserves in the Basin. The Dnipro Basin deposits are suitable for open exploitation of such categories as $A+B+C_1$ – 519.6 million t, C_2 – 8.9 million t; extra-balance – 32.0 million t. The balance reserves of $A+B+C_1$ categories, suitable for the deposits open mining, are concentrated mainly in the Kirovograd (254.5 million t – 49%) and the Dnipropetrovsk Regions (246.4 million t – 47%).

On the territory of the Dnipropetrovsk Region and partially in the neighboring regions there are three geologic-industrial districts: Verkhnyodniprovsk (partially in the Kirovograd and Zaporizhzhya Regions) – 19 deposits; Orihiv in the Zaporizhzhya and Dnipropetrovsk Regions – 2 deposits (*Orihivske and Sanzharivske*) and 4 areas, Kryvyi Rih in the Dnipropetrovsk, partially in the Mykolaiyiv and the Kherson Regions – 4 deposits (*Apostolovske, Veselo-Ternivske, Guriyske, Pichuginske*).

Geologic structure of the deposits is presented with spongy, sandy-and-clay rocks of Paleogene, Neogene and Quaternary ages of cover thickness up to 100 m varying mainly from 50 to 70 m, which fill depressions in crystalline foundations. The main coal-bearing concentration is attached to the Buchatska formation of the Eocene section of the Paleogene system. This factor determines the deposits and sections morphology, which have lens-like shape deposits of the complicated irregular configurations. Deposits extensions vary from several meters up to several kilometers.

General number of beds makes up from 1 to 3, average covering thickness accounts for 3–6 meter, up to 20 meter at maximum. Occurrence depth of coal beds varies from 10 to 150 meter. Coal is soft brown, humite and humite-lipto-biolithe.

Brown coal reserves of the Dniprovsk Basin and its distribution among deposits and administrative districts of the Region are shown in Table 3.

Occurrence of coal beds in the thickness of spongy sandy-and-clay rocks causes a strong water-cut of plots. The coefficient of rock moisture capacity of the normally operating enterprises usually makes up about 10 m^3 of water per 1 ton of coal extracted. Water-bearing horizons, which complicate the mining works, are distinguished into under-coal one which is located in the rocks of under-coal and over-coal bed which occurs higher of coal beds.

Brown coal is suitable for caking, semi-coking, gasifying, production of artificial earth wax.

The reserved plots for brown coal open-pit mining are at Verkhnyodniprovske and Synel'nykove deposits in the Dnipropetrovsk Region (Table 3).

At Verkhnyodniprovske deposit the reserves for open mining account for 146.44 million t. Mining and geologic conditions are favorable: coal bed thickness is 10.6 m; industrial coefficient of uncovering makes 6.6 m^3/t; humidity 51%; ash content 18.7%; bitumen content 8.3%; coal combustion heat 2290 kcal/kg. It is

possible to arrange a quarry here with annual output of 4.0-4.7 million t. Apart from favorable geologic conditions the deposit is located in ecological zone of the Dnipro river. Its allocation for mining may have environmental impact upon the river.

Table 3. Brown coal deposits of the Dnipropetrovsk Region.

Object location	Reserves by the end of 2017, thousand t			Extra-balance reserves
	$A+B+C_1$	C_2	Confirmed reserves $A+B+C_1$	
Reserved plots of "a" group for open-pit mines				
Petrivska Synel'nykove District	73284		73284	
Verkhnyodniprovska Verkhnyodniprovsk District	146443		146443	1673
Perspective plots for mines exploration				
Verkhnyodniprovsk District				
Sokolivska	0	72621		
Shyrokivska	47944		48255	7550
Pivnichno-Skhidna	0	95055		5866
№3 Deposit	4238		4238	2213
Novooleksandrivska the mine's field	72635	65599	72635	
Karnauhivska	203360	6940	44604	27004
№1-5 plots of the mine's fields	41652		41652	5632
№6 Deposit	24082		24082	2284
№1 Deposit	6490		6490	1589
Pivdenna	74600	7133	73864	14962
Pivnichna	50567		48555	5272
Petrykivka District				
Plots №1,2	84359		135905	61288
Plots№3-4	56384		109543	91036
Plots№5,6,	145956			183508
Synel'nykove District				
Pivdenna	69333	10705	69333	8915
Pivnichna	192598		157356	36559
Perspective plots for open-pit mine exploration				
Verkhnyodniprovska outside the technical bounds of open-pit mine	11927		11927	235
Petrivska Remained reserves of Synel'nykove Deposit	14008		14008	2058
Vacant plots near operating open-pit mines				
Verkhnyodniprovska outside the technical bounds of open-pit mine	784		784	69

Petrivska plot with reserves of 73.28 million t and 9.1 m^3/t coefficient of uncovering has been explored at Synel'nykove brown coal deposit with total reserves of 350 million t for open mining. Coal humidity is 58%; sulfur content – 4.8%; ash content – 20.8%; bitumen content – 7.4%; coal combustion heat amounts to 1810 kcal/kg. Mining and geologic conditions are difficult.

Other deposits in the Dnipropetrovsk Region were explored earlier and can be mined exclusively by the underground method.

Taking into account the tendency of curtailing the usage of nonrenewable natural resources the beginning of brown coal mining in the region is economically unreasonable.

2.3 Hard coal

Ukraine takes first place in Europe relating to hard coal reserves, its resources account for 117,2 billion t, and the explored coal makes up 45.8 billion t. Out of the explored reserves 25 billion t belong to the West Donbas. Within the territory of the Dnipropetrovsk Region there are deposits of Pavlogradsk-Petropavlivsk, Novomoskovsk and Petrykivsk geologic-industrial districts. Coal mining is carried out only in Pavlogradsk-Petropavlivka geologic-industrial district where 10 mines of JSC "DTEK Pavlogradvugillya" operate (Table 4).

Table 4. Coal output at JSC "DTEK Pavlogradvugillya" mines in 2018 [8].

Mine's name	Reserves by 01.01.2017	Output, t	+/- as to the preceding year
Stepova	1932289	231212	20194
Pavlogradska	45467	61005	-143495
Yuvileiyna	73306	133848	46924
Blagodatna	81420	139900	-30873
Ternivska	60892	119490	990
Samarska	77756	154429	13005
Dniprovska	127504	102362	-23080
Geroiyv Kosmosu	192406	265118	-452
West-Donbaska	233079	131100	-36556
Stashkov mine	51973	191079	91631

The area of the part of deposits being mined accounts for about 600 square kilometers. Industrial coal-bearing is attached to sediments of Samara formation C_1^3(C) of the lower part of Serpukhov layer of lower Carbon. Samara formation is characterized by a considerable development mainly of low-yield coal beds and interfacial layers. Coal beds are alternated with argillite, aleuroliths, sandstones and lime-stones.

Coal beds of C_1^3(C) formation of Pavlogradsk-Petropavlivsk geologic-industrial district corresponds to long-flaring; long-flaring and gassy; gassy brands. Coal of long-flaring brand is partially spread in the western part of Pavlogradsk-Petropavlivsk geologic-industrial district, long-flaring an, gassy – mainly in the central part and gassy brand – in the eastern part. Coal of "Geroiyv Kosmosu", "Blagodatna", "Pavlogradska", "Ternivska", "Dniprovska" mines belongs to long-flaring, gassy brand, the rest – to gassy brand. Coal of long-flaring brand can be used as energy and municipal fuel with a prospect of using it in chemical and partially in coke-chemical industries. Coal beds of Samara formation of gassy brand in Pavlogradsk-Petropavlivsk district, as of that in West Donbas in general, do not differ for their petrography content from coal of long-flaring, gassy brand. In the long term the coal reserves of long-flaring, gassy brand are a basis for production of squeezed coke and obtaining synthetic fuels. At present

the main purpose of coal use is power engineering. The main purpose of gassy brand coal usage in the eastern part of Pavlogradsk-Petropavlivsk geologic-industrial district is in coke-chemical industry.

A considerable part of the area under extraction comes to the river overflows, industrial and civil objects. Under the overflows of the Samara, Ternivka, Mala Ternivka rivers 186.3 million t of coal are bedded and under civil and industrial structures – 412 million t [7]. Such settlements as Blagodatne, Verbky, Ternivka, Rosyshky, Samarske and others get location in mining zone. Moreover, in the area of coal mine fields there runs Kyiv – Donetsk motor road and the railway sections.

The potential capabilities for increasing energy and coke coals are available in the Dnipropetrovsk Region.

Large reserves of energy coal are concentrated in Novomoskovsk District, but this coal belongs to a saline one. It has an increased content of water-soluble salts of sodium inherited from the marine conditions of coal accumulation [7].

Taking into account the world tendencies towards curtailing the use of energy coal, its production must be carried out within the volumes of existing needs. Hence, due to available technologies, steel production retains the need of steadily supplying the industry with coke coal. Therefore, there is an acute problem of technological re-equipment in coal mining industry, which will allow optimizing coal output volumes in the region.

3 Alternative sources of hydrocarbon raw materials

3.1 Methane gas of coal deposits

In the context of energy source diversifying the problem of utilizing alternative types of hydrocarbon raw materials arises acutely. Coal-bearing deposits of Donbas (coal beds as well as coal-bearing rocks), which contain methane considerable resources, can serve for its industrial production and should be taken up as gas-coal deposits. Methane of coal deposits is a widespread energy raw material and its reserves are rather huge, and the real volume suitable for extraction exceeds 3.0–3.5 trillion m^3, which overruns substantially gas reserves of the rest fields of Ukraine. It is necessary to carry out gas-coal deposits mining in an integrated way for separate extraction coal and methane. In so doing, the methane resources are estimated as an accompanying useful mineral. It is technologically necessary to remove it for providing safe works during coal mining operation, or as an individual useful mineral which is extracted irrespective of coal beds mining on the principles of economic feasibility and profitability.

By the assessment of national and foreign experts, Ukraine takes the fourth place in the world after China, Russia and Canada for its methane reserves potential at coal deposits.

Total resources of the mine methane in rocks and coal beds vary by different assessments from 4-6 up to 22.2 trillion m^3. The industrial share makes 11.9 trillion m^3 out of 3.3 trillion m^3 forecasted are suitable for extraction [9]. A considerable part of total methane reserves in coal-bearing rocks makes up occluded and fixed methane for extracting of which introducing efficient technologies for mining worksand technical tools by using foreign countries' experience are required.

Methane as an accompanying useful mineral is contained in coal beds of Carbon age in the east of the Region within Pavlogradsk-Petropavlivsk geologic-industrial district. Natural methane-bearing capacity of coal-bearing deposits changes, at average, from 5 up to 30 m^3/t of dry ash-less mass [7]. Coal beds are characterized by primary and post-sedimentation folding and are natural traps, where methane is in a free condition. The depths from 350 m to 1000 m are considered optimal for methane extraction out of coal beds of low-medium and medium grade of metamorphism. The mines of Pavlogradsk-Petropavlivsk district of West Donbas correspond to such geotectonic conditions. Regional strata dislocation is not high, thickness up to 3 km with minor cata-genetic transformations, increased porosity and perviousness. Coal beds covering consists of rocks containing aleurolite-and-argillite with minor layers of sandstones, which enables methane conservation. Collectors of methane serve fractured reservoirs [10]. Coal mine fields of Pavlogradsk-Petropavlivsk district are located within the Central graben (sunken block) and are limited by Shevchenkivskyi and Bogdanivskyi faults. Coal beds plunge in monoclonal way at an angle 3-5° to the north, north-east with rocks strike in the western and north-western directions. During research it was determined that positive gas anomalies within Geroiyv Kosmosu mine of Pavlogradsk-Petropavlivsk district are located within synclinal flexure, which stretches alongside Bogdanivskyi fault. Positive anomalies of free methane content deviation on the mine's field are connected with synclinal folds, one of which was formed near Bogdanivskyi fault and another – in a syncline wing near Blagodatnenskyi fault. Separate anomalies are situated within great anticline structure. Data statistics processing of nine mines' fields in Pavlogradsk-Petropavlivsk district performed by N. Khomenko showed that in folds and wings of syncline structures over 50% of additive gas-bearing anomalies and 67% anomalies with free methane content concentrate [10].

Research works for studying possibilities of industrial extraction methane from Donbas coal thickness with selection of plots for setting up pilot projects were carried out [11] among the others in Petrykivka-Novomoskovsk area (southern bench of marginal through part of the Dnipro-Donetsk depression) and in Pavlogradsk-Petropavlivsk (in the southern zone of Donbas minor folding).

In Pavlogradsk-Petropavlivsk district the resources of HC (hydro-carbonaceous) gases in coal beds and layers in the operating mines (mine fields) account for: in coal 11.7 billion m^3, in satellites СК = 0.5 (total) 6.1 billion m^3 with reservoir thickness of 0.3 m – 2.3 billion m^3, (on the exploration plots) in coal 4.4 billion m^3, in satellites (total) 5.8 billion m^3, with reservoir thickness of 0.3–2.3 m.

Comparing to other geologic-industrial districts of Donbas, where hydro-carbonaceous gas resources were

calculated, Pavlograd-Petropavlivsk district is characterized by mean values of the reserves (18 billion m^3). It is suggested to be considered as a territory of the second turn, which must be developed by using an experience obtained on the territories of the first turn [10].

The present geologic survey works (GSW) with the purpose of developing methane extraction technologies from coal beds are carried out on 16 plots in coal-bearing Donbas under special permission. But the lack of occluded and tied gas extraction technologies does not allow to expect positive results of geologic survey works (GSW) due to the obvious absence of technical-and-technological equipment required for these kinds of works.

Research-and-commercial extraction of methane-gas is carried out in Lysychansk-Toshkivka area, where methane output amounted to 0.84 million m^3 in 2017. Methane loss due to coal mining amounted to 126.52 million m^3 in 2017.

3.2 Shale gas

Considerable perspectives for further increasing resource base of hydrocarbon gases in the Region and in the state in general are associated with shale gas resources development [9].

By the assessment of [9] who researched relationships of spatial and age-related rock expansion for perspective shale gas in Eastern oil-gas-bearing district of Ukraine within north-east part of the Dnipropetrovsk and partially of the Kherson regions there was singled out Zakhidnomykhailivsko-Pivdennoblyznyukivska perspective zone. It is attached to the southern Dnipro-Donetsk depression/fault rim. The zone extent makes up 128x24 kilometer approximately. Occurrence depth of sediments covering of Lower Carbon here varies from 1500 to 4000 m.

Within the Dnipropetrovsk Region there are located Bagatoiska, Pereschepyne, Lychkove, Kremenivka, Kotivka, Kateryniva, Kernosivka, Mykhailivsko-Pivnichnominivska, Leventsivka areas, in which mainly of them traditional oil-gas fields are exploited. Sediments of Lower Carbon, Upper-Vize and Lower-Serpukhov sub-layers are perspective ones for shale gas exploration on this territory [11]. In the cut of Upper-Vize sediments the perspective clay thickness are made up mainly of dark-grey and up to black argillites. Lower-Serpukhov sub-layers rocks are presented mainly by dark-grey argillites with minor interfacial layers of aleurolite, sometimes siderites or hard coal. By prior assessments [9] the production resources of shale gas of low-hard coal clay sediments within the whole perspective zone of 3027 square kilometers amount to 1756.7 billion m^3 including free gas – 801.3 billion m^3 and occluded gas– 149.9 billion m^3. Resources density on this territory amounts to 580.3 million m^3, sediments occurrence depth is in the interval of 2500–4300 m. By its geologic-production criteria Zakhidnomykhailivsko-Pivdennoblyznyukivska zone is the top-priority object for geologic-surveying works in shale gas exploration [9].

4 Perspectives of energy industry development in the Dnipropetrovsk Region

Thus, the ensuring its own fuel-energetic resources and their consumption within the Region are obviously unbalanced: steady power supply and efficient utility of energy resources in the Dnipropetrovsk Region are of top-priority problems which demand solution in order to exclude the drop in economic and social development of the society.

It is worth mentioning the following factors that influence energy efficiency of the Region's economy:

1. domination of power-consuming industries in economic structure;
2. tear and wear of fixed assets and out-of-date technologies;
3. the absence of the unified monitoring system and control over energy consumption;
4. the lack of introducing innovative technologies mechanisms;
5. the absence of anti-monopoly mechanisms at national and regional levels.

Energy efficiency of economy is directly connected with the use of fuel-energy resources (FER) nature, which must ensure steady economic development. National researchers understand the steady economic development as satisfying the needs of social-economic systems without limiting possibilities of the coming generations with regard to satisfying their needs [3, 12]. So, FER utility and energy efficiency should be considered in view of the concept of ecological efficient production, ecologically justified consumption and efficient management [3].

Experts mark out several criteria of FER rational usage [3]:

1. minimizing resources loss in the processes of production, supply, distribution, transformation and consumption;
2. attraction and utilization of secondary energy resources and waste products for their production;
3. development of market mechanisms in the sphere of ensuring and using energy resources;
4. increasing efficiency of FER consumption at the cost of introducing efficient technologies and increasing FER consumption efficiency;
5. maintenance of FER incremental value per capita in order to provide saving of natural capital value;
6. widening the sphere of utilization renewable energy sources in FER production and consumption;
7. limitation the government's interference which threatens unbalancing market regulation mechanisms of FER consumption and socio-economic development.

Providing energy safety of the Dnipropetrovsk Region as an industrially developed district at the expense of increasing energy efficiency in economy and developing alternative power industry is one of the top targets of the Dnipropetrovsk Region Strategy Development for the Period up to 2035, which is the basic document of the region's power engineering development. The Strategy envisages taking into account

the economic, social and environmental priorities of energy-saving, energy efficiency and the region's power engineering development.

As mentioned above, high fuel consumption and a large portion of mineral fuel in the region's energy balance together with out-of-date technologies and inefficient exhaust gas-cleaning systems lead to high level of atmospheric pollution. That is why the major strategic targets [6] of the Region's power engineering development are determined as follows:

1. energy safety (planning of measures related to energy-saving and increasing energy efficiency level, decreasing GRP energy consumption capacity and energy renewal sources development);
2. "green" economy (promotion economic growth and decreasing power unbalance owing to renewal energy development);
3. clean environment (improvement of the human environment and quality of life).

So, in 2018 on the territory of the Dnipropetrovsk Region 13 solar power stations (SPS) were put into operation amounting to 38 units in total. In 2018 SPS of the region produced 37 million kW/year of electric power, which corresponds to annual consumption by Novomoskovsk District. The most powerful solar station operates in Nikopol (32 screens of 10 MW output) built by investors from Canada (project cost EUR 11 million). Chinese investors are building SPS for EUR 230 million near Starozavodske village of Nikopol District.

On the Region's territory six biogas installations have been put into operation and the development of wind-power engineering is being planned.

5 Conclusions

The analysis of consumption and energy resources ensuring of the Dnipropetrovsk Region performed by us allows to state as follows:

1. In the structure of the Region's consumption energy resources hard coal prevails (39.2%), coke and semi-coke of hard coal; gas coke (28.6%) and natural gas (13.8%).
2. The main consumers of energy resources in the Region are steel producers, the share of which amounts to 63.1% of total volumes of consumption, electric power stations, population and industrial enterprises.
3. In the Region there is actual unbalance between the levels of ensuring own natural gas resources and its consumption which demands investment into exploration and mining works at the deposits of traditional and alternative energy carriers.
4. At present, brown coal mining at the known deposits in the Region is not reasonable due to the limit of their reserves and of problematic methods of their extraction.
5. In the Region there are potential possibilities for increasing output of both hard coal and coking coal, but its mining should be limited to the available volumes. Technological re-equipment became actual in coal mining industry, which will allow optimizing coal extraction in the Region in view of ecology problems.
6. Methane as an accompanying useful mineral is present in coal beds of Carbon age in the north of the Region within Pavlogradsk-Petropavlivsk geologic-industrial district.

The district with average values of the reserves (18 billion m^3) is proposed to be considered as a territory of the second turn, which must be developed by using an experience obtained in gas extraction on the territories of the first turn with considerable reserves.

7. For the perspective exploration of shale gas in the Region are sediments of Lower Carbon, in particular Upper-Vize and Lower-Serpukhov sub-layers on the territories where traditional oil-gas deposits are exploited. Top-priority object to carry out geologic explorative works for shale gas is Zakhidnomykhailivsko-Pivdennoblyznyukivska zone. The production resources of shale gas of low-hard coal clay sediments within the whole perspective zone amount to 1756.7 billion m^3 including free gas – 801.3 billion m^3 and occluded gas – 149.9 billion m^3.
8. The solution of the problem of energy intensive industries in the Dnipropetrovsk Region has a complex character and requires finding efficient solutions concerning regulation of energy resources consumption by using stimulating, compulsory and educative measures. Top-priority directions of the state and regional policy in the sphere of energy-saving must be decreasing energy intensity and introducing alternative types of energy.

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Photovoltaic and wind energy: challenges and solutions in desert regions

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Abstract. In desert areas, some challenges have the prospective to reduce photovoltaic energy production. These are the creation of finely crusted carbonates and/or mud coatings resulted from fallen aerosols and dust during humid conditions. These challenges that greatly affect solar panel planes, as well as wind turbines, were allocated to accomplish the practicability to establish wind and/or photovoltaic energy systems in Kuwait. It was concluded that solar cells are not the best appropriate energy source in Kuwait due to the above-listed challenges; therefore, substitute renewable energy types are considered more practicable. After one year of operation at photovoltaic units and wind turbines in Kuwait, the outcomes show that wind turbines record production energy numbers that go beyond the production average. This was connected with high capacity factors during one year, consequential in an annual power production that is 2.3 times greater than that of solar panels; running 450 homes compared to 199 homes for photovoltaic (PV). Bubiyan Island and west of Kuwait are the most suitable potential location for wind farm establishment. Several control measures including the establishment of green belts and plantation of native shrubs were found proper in reducing dust by 64.5% and 68.4, respectively.

1 Introduction

Globally, the consumption of wind and solar energy is expected to increase more than any other mid-century energy source [1]. Solar and wind energy as a renewable energy source, therefore, conquer the peak between various alternative energy sources and are slowly adapted in multiple applications [6]. In desert regions, several environmental problems affect the photovoltaic panel such as darkness, air pollution and dust. Wind and photovoltaic energy are quiet, abundant, environmentally friendly, and a renewable energy source [8]. Solar radiation, dust and relative humidity in the Middle East have a negative impact on the Arabian Gulf region [13]. Such a challenge is common in nature and is therefore likely to apply passive and active approaches in desert regions according to their specific conditions [9]. At a certain geographic location, awareness of these challenges is vital in establishing any clean energy systems and in estimating their output and efficiency [3]. Awareness of these challenges is also a prerequisite for all solar and wind systems to be modeled and planned and valuable for studies on the balance of atmospheric energy, air quality and climate [14]. The concerns of social public engagement and sustainable expansion in the region, solar energy development are discussed along with the necessity to develop the human capital needed to address alternative photovoltaic energy challenges from a technical and social point of view [10]. In addition, wind energy efficiency problems require the careful attention of wind properties such as average wind frequency distribution and speed [14].

The Gulf Countries (Saudi Arabia, Qatar, Kuwait, UAE, Oman, and Bahrain) are at peak loads deficiency and high risk of power, in addition to consuming oil and gas resources to meet increasing energy demand [4]. In Kuwait, environmentally clean energy systems will lead to a modern electrical network, more job opportunities, a more efficient power supply, and a better regional image in a cleaner environment [11]. Among the many alternative renewable energy sources, photovoltaic power generation is the most practiced in the Arabian Gulf countries [2]. The monthly solar consumption in Kuwait is approximately 9-11 hr/d with a mean daily solar insolation of more than 7.0 kWh/m^2 [8]. On the other hand, aeolian dust is a common weather phenomenon in marine and terrestrial [1] environments within Kuwait. In the northern Arabian Gulf, including Kuwait, there are more dusty days compared to the southern part [5]. In Kuwait, the mean total annual dusty days is 255 days which definitely will act as a challenge for solar power generation in the region. Therefore, place Kuwait as an ideal location for investigating the significant effect of dust and weather challenges on the generation of solar and wind energy generation. The aim of this study is to determine the potential feasibility of setting up solar and/or wind energy systems in Kuwait focusing on the environmental challenges. This study covers successful control measures that were applied to control or minimize the effect of such challenges.

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2 Methodology

2.1 The depositional dust rates and weather data

In Kuwait, humidity and average solar radiation data (2010-2016) were attained from 9 weather stations. The solar radiation was measured via the Li-COR pyranometer fixed at a 10-meter above ground level in all weather stations.

Fallen dust amounts were monitored for two years (September 2009 – August 2011) from 47 locations in Kuwait using dust collectors following Reheis (1995) design that was (Figure 1). The trap is 240 cm in height and with a 20 cm radius from ground level (Figure 2). The deposited dust was collected every month from all traps.

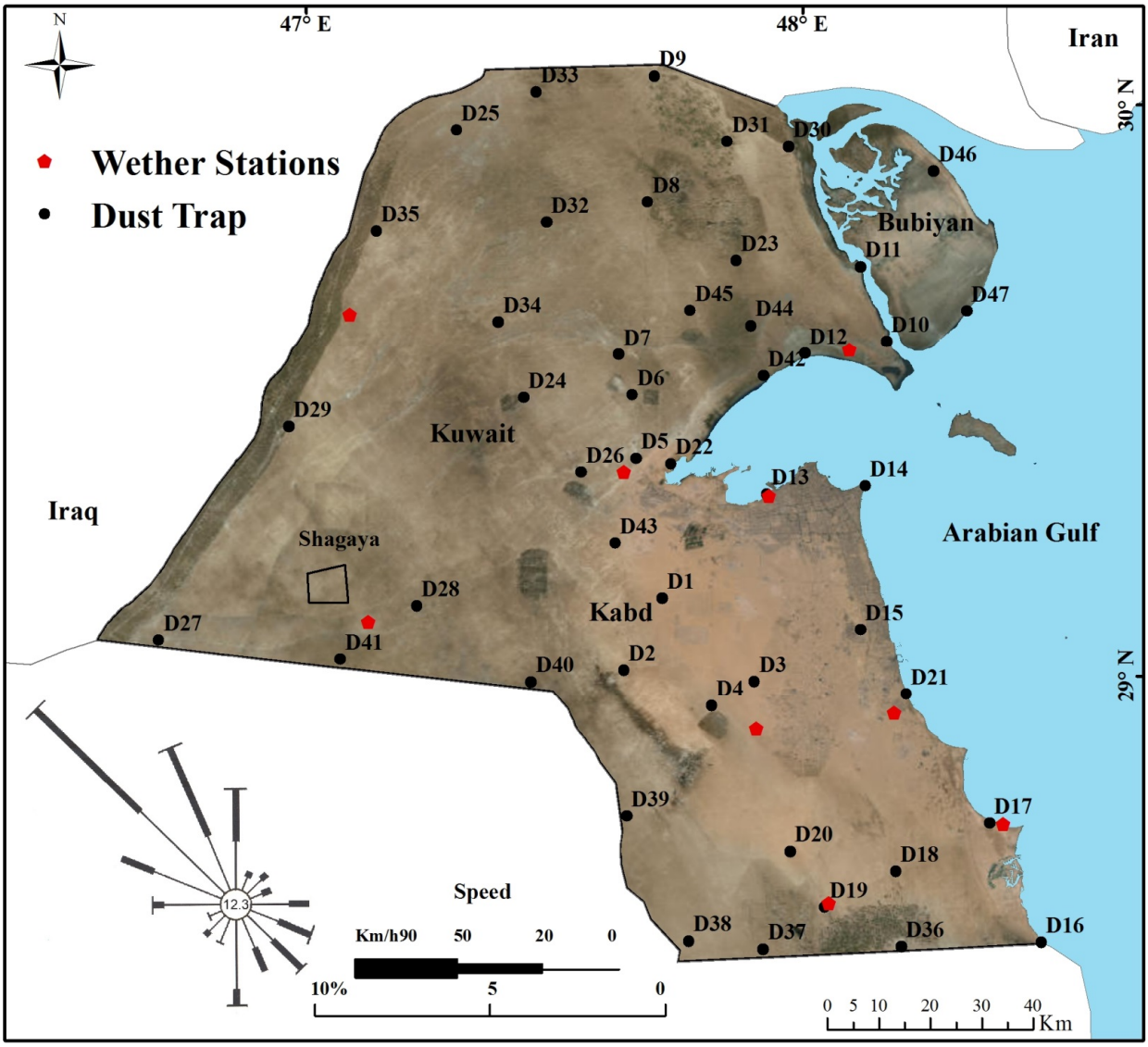


Fig. 1. Location map for the weather (1958-2016) and dust (2009-2011) monitoring stations with the average wind rose for Kuwait and showing the Shagaya area.

The wind and solar energy power plants with 10MW capacity each, located in the Shagaya area west of Kuwait were compared (Figure 3). The wind is represented by five wind turbines (2 MW for each) that were fixed near the photovoltaic energy unit. The wind and PV farms were studied from an economic point of view with reference to their Levelized Cost of Electricity. The monthly capacity factor was calculated for a one-year operation (June 2017 to July 2018). Annual production of both plants was measured; Capital Expenditure and operation expenditure were taken into concern throughout the life of the plants together with Investment cots.

2.2 Carbonates and Mud in dust

Dust fallout particle size percentages were identified via sieve mesh (63 micrometers) to separate sand from mud for all samples for four months (November, August, May and February 2010). Also, the carbonates (mainly calcite and dolomite) within collected dust samples during

March, June, September, and December were identified using Philips PW-1830 X-ray diffraction (XRD).

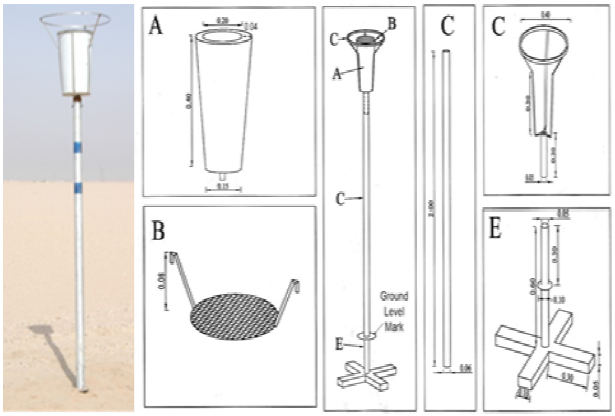


Fig. 2. The dust trap (left photo) and diagram (right sketches).

Fig. 3. Dusty solar panels compared to cleaned panels at the KISR.

2.3 Mapping

The collected data for depositional dust rates, mud and carbonates percentages, humidity, solar radiations, and wind were stored as layers using the ArcGIS S/W software, and geostatistical interpolator (Simple IDW method) was steered to create the annual average distribution maps.

Approximately 110 thousand native plants (*Haloxylon salicornicum*, *Lycium shawii*, *Nitraria retusa*, and *Calligonum polygonoides*) were planted at a 3-m average distance between plants in highly degraded land with no vegetation. Both five sand and dust traps were fixed (2 at 100 m downwind, 2 at 100 m upwind, and 1 in control area) for monitoring the aeolian deposition (dust and mobile sand) monthly for four years (September 2011–August 2015).

3 Results and Discussion

The annual dust deposition rates are 149-576 t km^{-2} (average is 339 t km^{-2}) in 2010-2011 and 10-1065 t km^{-2} (average is 216 t km^{-2}) in 2009-2010. The average dust rate maps were delineated based on the average annual dust deposition in two years 2009-2010 (Fig. 4a) and 2010-2011(Fig. 4b). These maps show momentous trends in dust accumulation over the two years of monitoring. The maps classify specific spaces with high (more than 350 t km^{-2}) and low dust deposition in the two years, but the spaces with high dust deposition extend to cover more places in 2010-2011 compared to 2009-2010. This will surely will affect solar energy in Kuwait and the surrounding regions. The effect of dust on solar or wind energy production was globally and regionally addressed by many researchers.

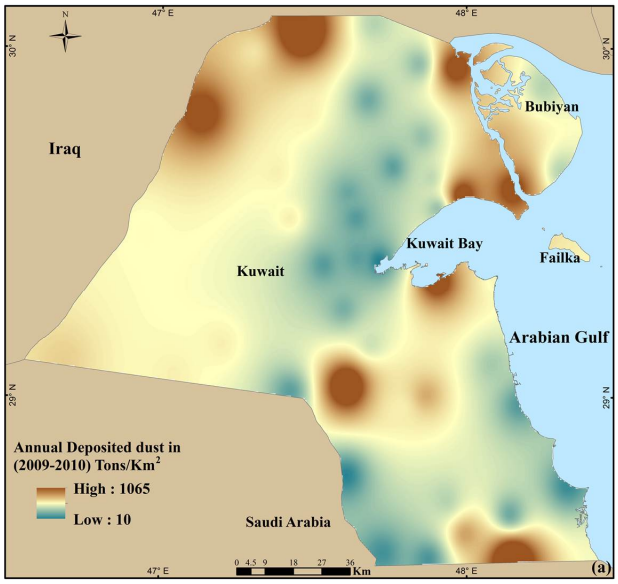
The deposition of dust on surfaces of photovoltaic cells can increase cleaning cost which is considered necessary to ensure the minimization of efficient operation and power leakage. Dust deposits on photovoltaic cells, combined with a lack of water sources in the desert regions to clean the solar-power system will add a variable cost for cleaning services. Dust can have a damaging effect on the operating potential of photovoltaic plants. Dust was revealed to degrade the energy delivery, which in turn causes a decrease in the energy output of photovoltaic cells by 15% to 30% [15]. Power fall can even reach 100% during humid periods with dust concentration by water-soluble salts.

3.1 The mud content

The mud is particles that are less than 4 phi (0.063 mm) in size diameter. Mud contains two major size fractions; these are silt and clay. It was noted that the southern areas in Kuwait contain fewer mud percentages compared to northern Kuwait. Deposited dust during February revealed the lowest mud ratios when compared to other months, while November and August revealed the highest. The annual mud percentages present in accumulated dust range from 10-95%, with 63% as an average (Fig. 4c). Globally, the mud highest percentages (≥ 85%) within dust are recorded in Cairo – Egypt, Um Qasir – Iraq, Manamah – Bahrain, Cartagena – Colombia, and Bald Hill – Australia.

3.2 The carbonates content

Carbonates and quartz form the main constituent of dust mineralogy in Kuwait (Table 1).



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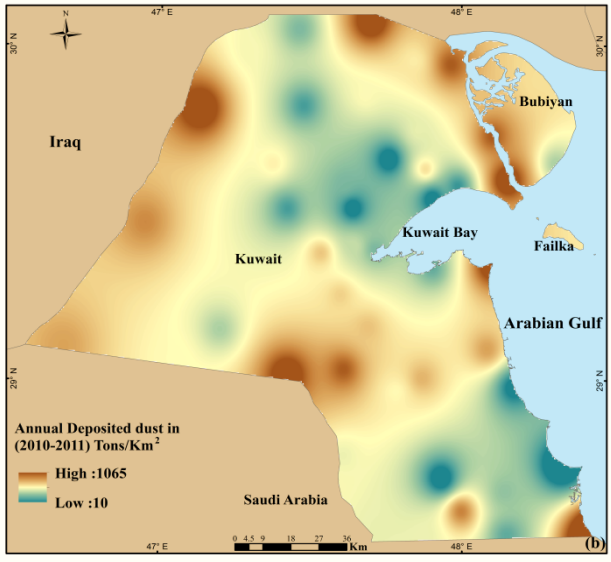

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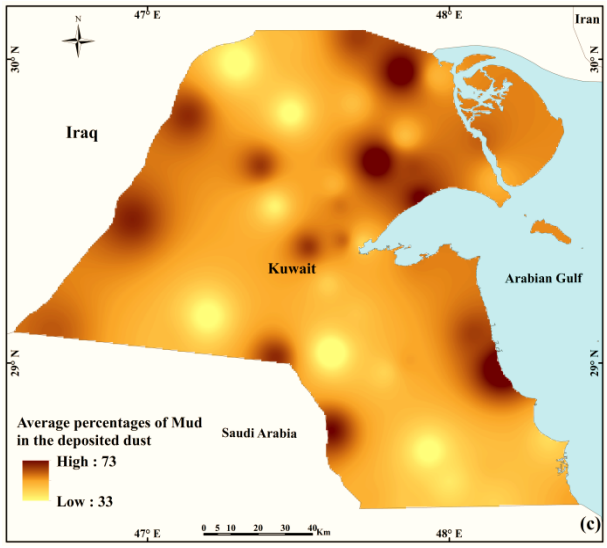

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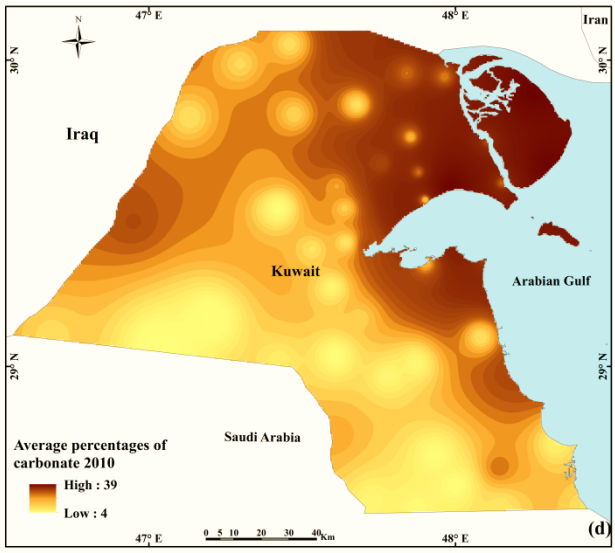

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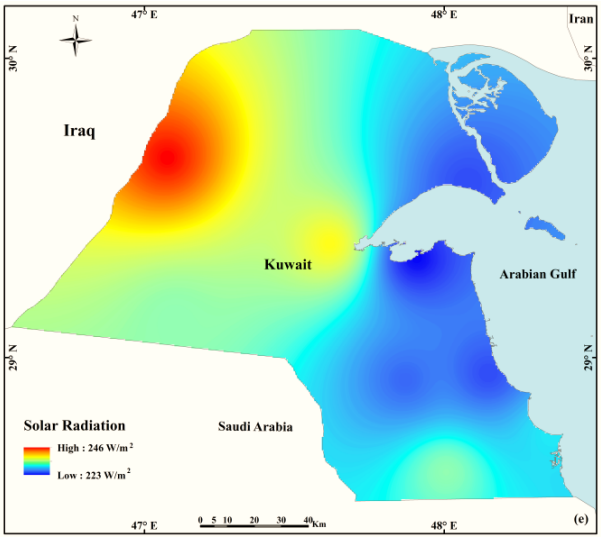

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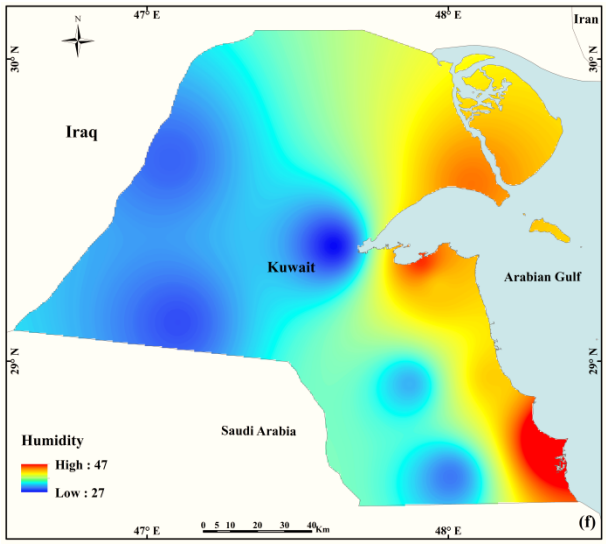


f

Fig. 4. Maps for annual deposited dust in 2009-2010 (a) and 2010-2011 (b), average mud and carbonate percentages within dust (c, d), and average solar radiation and humidity (e, f).

Table 1. The mineralogical percentages and average particle size of dust in Kuwait compared to global dust samples.

Location	Particle size %		Minerals %				
	Sand	Mud	Carbonates	Quartz	Feldspars	Clay	Others
Kuwait	37	63	45	38	10	2	5
Ain – Emirates	97	4	52	26	20	1	0
Dubai – Emirates	17	82	45	21	6	0	27
Ahwar – Iraq	3	97	80	13	8	0	0
Manama – Bahrain	12	87	41	32	10	3	15
Walameen – Saudi Arabia	40	61	13	62	24	1	0
Amman – Jordan	30	70	68	21	4	0	7
Tripoli – Libya	20	81	27	64	5	4	0
Biougra – Morocco	12	88	46	46	8	1	0
Cartagena – Colombia	10	90	0	66	33	0	1
Bald Hill – Australia	9	90	0	57	21	14	7
Cairo – Egypt	10	90	34	51	15	0	0
Average	25	75	38	41	14	2	5
Maximum	97	97	80	66	33	14	27

The dust contains higher carbonate percentages during October-April reaching up to 58%. The presence of higher carbonate percentages acts as a good indication for low aeolian activity during summer (May-September). The northwestern and western areas show the lowest percentages down to 5% of the total mass of dust. The average annual carbonate percentages within the deposited dust range from 4 to 36.8% with 27.6% as average (Fig. 4d). The highest carbonate percentages are in the northeastern parts of Kuwait and coastal areas. Kuwait, Bahrain, and Dubai contain nearly similar amounts of carbonates in dust samples. On the other hand, carbonates vary a lot in other regional areas such as Al-Ahwar and Um Qasir – Iraq (Table 1). This is attributed to the dust storms that originate from Iran and Iraq is rich in mud and carbonates [7].

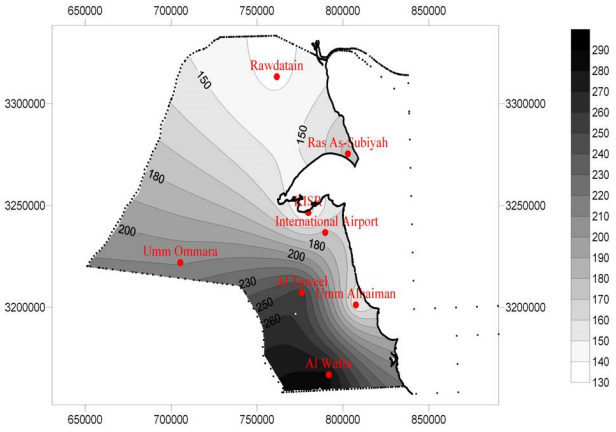
3.3 The solar radiation

The average annual solar radiations on the horizontal surfaces in Kuwait are represented geographically (Fig. 4e). The average annual solar radiation ranges from 223 Wm^{-2} to 246 Wm^{-2} which is so low. The northwestern and north areas in Kuwait reveal higher solar radiation compared to other areas.

The average humidity similar to solar radiation, coastal areas show higher percentages while other areas show lower humidity percentages (Fig. 4f). The carbonates and/or mud mixed with humidity causing the development of a thin-crust layer on solar panels that are difficult to clean. Numerous cleaning can effect, scratch and damage to solar panels.

3.4 Solar photovoltaic (PV) and wind energy

After one year of operation at photovoltaic units and wind turbines in Kuwait, the outcomes show that wind turbines record production energy numbers that go beyond the production average. This was connected with high capacity factors during one year, consequential in an annual power production that is 2.3 times greater than that of solar panels; running 450 homes compared to 199 homes for PV (Figure 5, Table 2).



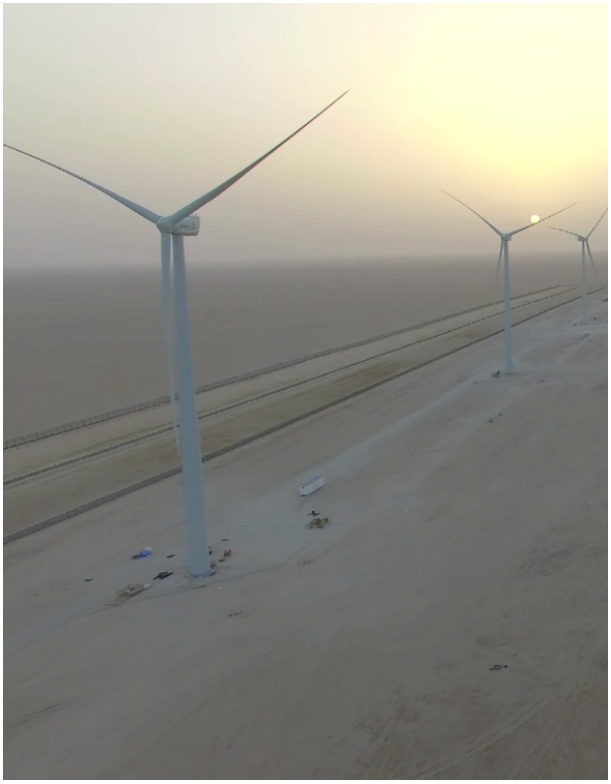


Fig. 5. A map for wind power density W/m^2 distribution over Kuwait at a height of 30 m (top) and the wind turbines in the Shagaya area at western Kuwait (bottom).

Similar to solar radiation, coastal areas show higher percentages while other areas show lower humidity percentages (Fig. 4f). The carbonates and/or mud mixed with humidity causing the development of a thin-crust layer on solar panels that are difficult to clean. Numerous cleaning can effect, scratch and damage to solar panels.

Table 2. The Shagaya Wind and PV Farms economic results.

	Wind Farm		PV Plant	
Generation	42,590,000	KWh	18,830,000	KWh
CAPEX	5,595,000	KD*	5,488,365	KD
OPEX PV	5,192,896	KD	3,649,763	KD
LCOE	0.0152	KD/kWh	0.0269	KD/kWh
	15.2	fils/kWh	26.9	fils/kWh
	4.62	USD/MWh	8.15	USD/MWh
Discount	7%			
Years	25			
Exchange	3.2988			
CAPEX	5,595,000	KD	4,613,856	KD
Year 1	62,102		145,991	
Year 2	62,102		145,991	
Year 3	268,281		145,991	
Year 4	268,281		145,991	
Year 5	268,281		145,991	
Year 6	268,281		145,991	
Year 7	268,281		145,991	
Year 8	268,281		145,991	
Year 9	268,281		145,991	
Year 10	268,281		145,991	
Year 11	299,233		145,991	
Year 12	299,233		145,991	
Year 13	299,233		145,991	
Year 14	299,233		145,991	
Year 15	299,233		145,991	
Year 16	142,628		145,991	
Year 17	142,628		145,991	
Year 18	142,628		145,991	
Year 19	142,628		145,991	
Year 20	142,628		145,991	
Year 21	142,628		145,991	
Year 22	142,628		145,991	
Year 23	142,628		145,991	
Year 24	142,628		145,991	
Year 25	142,628		145,991	

*KD : Kuwait Dinar

4 Conclusions

The Arabian Gulf governments recently proposed a strategy for the expansion in using sustainable energy mainly photovoltaic energy with a more ambitious vision to act as a solar and wind energy exporter. This study has positively identified the surrounded challenges that can disturb the performance of photovoltaic technologies in the desert region. On the other hand, the development of photovoltaic energy units in Kuwait and the Gulf countries should take into concern environmental challenges, such as fallen dust, and mud, carbonates, humidity, and solar radiation. The effect of dust (depositional rates, mud and carbonate contents), solar radiation and humidity on the power efficiency of photovoltaic panels were observed. Therefore, wind as an alternative source of energy would be more feasible. The Bubiyan Island, southwestern and western sides of the state of Kuwait and southern are the potential sites for wind farm establishment. Several control measures including the establishment of green belts and plantation of native shrubs were found proper in reducing dust by 64.5% and 68.4, respectively.

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Optimization of air chamber in solar air collector

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Abstract. Recently, environmental problems have become more acute. In 1980, the International Union for the Conservation of Nature (IUCN) prepared the World Conservation Strategy. This document interpreted the term "sustainable development" as an inseparable link between social development and nature conservation. And already in 1992, after the United Nations Conference on Environment and Development, the concept of sustainable development gained a leading status. The conference materials determined that sustainable development is a development of a society that meets the needs of today without compromising the ability of future generations to meet their own needs. Therefore, being aware of the need for energy conservation, there is increasing emphasis on the use of solar energy throughout the world to generate electricity and heat.

1 Introduction

The potential of solar energy in Ukraine is sufficiently high for widespread use both heat-and-power engineering and photovoltaic systems in almost all regions. The period of functional operation of solar heating systems in the southern regions of Ukraine is 7 months (from April till October), in the northern regions it is 5 months (from May till September). Photovoltaic equipment can be used very effectively throughout the year [1, 2].

For solar heating in climate weather conditions of Ukraine, the exploitation of flat solar collectors that use both direct and diffuse solar radiation is effective. Concentrating solar collectors can be quite effective only in the southern regions of Ukraine.

The use of renewable source of energy in Ukraine and in the world is gaining momentum. Solar collectors are increasingly popular. However, prefabricated collectors are quite expensive and their payback period is significant. Therefore, many engineers are working on simple and lowcost designs.

Solar collectors are a number of devices with some differences in types, shape, types and purpose. There are two main types of solar collectors as liquid and air. Solar air collectors are often plain flat collectors.

The main advantages of air collectors are their simplicity and reliability. Such collectors have a simple structure. With proper care, a quality collector can work for 10-20 years, and it is very easy to manage. The heat exchanger is not needed because the air does not freeze.

On Fig. 1. shows a map of solar radiation power on horizontal surfaces within Ukraine. In the Eastern and Southern regions, solar installations will be significantly more efficient.

A potential way to reduce the cost of collectors is their integration into walls or roofs of buildings, as well as the creation of collectors that can be assembled from prefabricated components.

Fig. 1. Global Horizontal Irradiation for Ukraine (The World Bank, Solar resource data: Solargis, 2017).

These collectors are often used for heating. However, the opportunity to get cheap thermal energy in the summer has led to a wide range of applications of such installations for drying agricultural products. Therefore, research in this direction continues to these days [3-7].

The benefits of solar air collector:

1. Additional protection of facade (roof) materials from ultraviolet radiation.
2. Installation of skewed canopy (porch, parking space) while receiving house solar heating with solar collector is possible.
3. Saving energy. Cleaning air circulation. Highly efficient heating.

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Today the most common are the following designs of available air solar collectors: with the movement of the air through the air chambers of various forms (Fig. 2), with the movement of the air in the space between the bottom of the case and solid screen absorber (Fig. 3), and with the movement of the air between the glass and bottom absorber on a fixed path (Fig. 4).

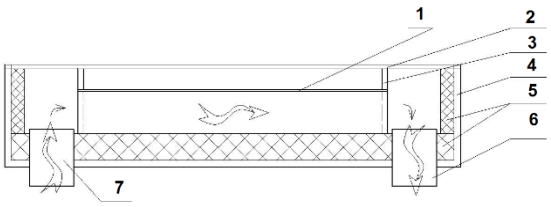

Fig. 2. Collector with the air passing through air chambers: 1 – air chamber; 2 – glass; 3 – baffler; 4 – body; 5 – insulation; 6 – air outlet; 7 – air intake.

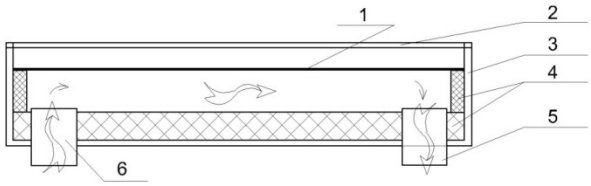

Fig. 3. Collector with the air passing between the bottom of the case and solid screen absorber: 1 – absorber; 2 – glass; 3 – body; 4 – insulation; 5 – air outlet; 6 – air intake.

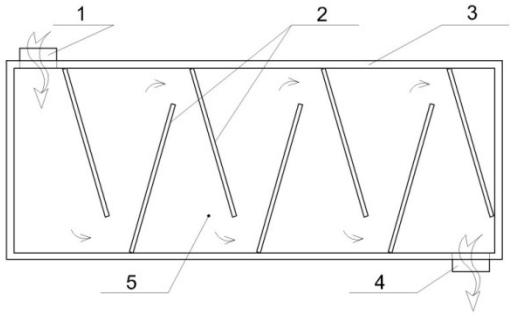

Fig. 4. Collector with the air passing between the glass and bottom absorber on a fixed path: 1 – air intake; 2 – baffler; 3 – body; 4 – air outlet; 5 – absorber.

Air passes through the absorber due to natural convection or under the influence of a fan. Since air conducts heat worse than liquid, it receives less heat from the absorber than the liquid coolant. In some solar air heaters, fans are attached to the absorber, which provide air passage and improve heat transfer. The disadvantage of this construction is that it consumes energy to operate the fans, thus increasing the cost of the system operating. However, the use of solar panels to power the fan, eliminate this disadvantage. In cold climates, the air is directed to the gap between the absorber plate and the insulated rear wall of the collector: thus avoiding heat loss through transparent surfaces.

Solar air collectors are simple devices, however have a numerous of options of constructive execution, warming, a material and a covering of an absorber, a translucent covering, and means of ensuring creation of turbulent air streams inside. Therefore, a large number of scientific studies of various authors is devoted to the study of their properties and design features [8-11, 16-19].

Proper orientation of solar collectors (direction and angle) increases their productivity. The earth's atmosphere absorbs and reflects a significant portion of solar energy. Therefore, the maximum amount of energy comes at noon, when the direct rays' stream is least delayed by the atmosphere. In the northern hemisphere geographical south is the best direction at noon, while the sun's rays strike perpendicularly upon the collector. A simple geometric calculation shows that the collector should be inclined to the horizon on the value of the latitude of ± 10 angular degrees. For example, in Kyiv, 50° 25' north latitude, which means that the angle can be 40 to 60 angle degrees [12-15].

Azimuth characterizes the deviation of the collector surface from the south; at the orientation of the collector surface straight to the south, the azimuth = 0. Since the insolation in the middle of the day is the most intense, the collector surface should be oriented to the south as far as possible. However, good results are also achieved by the deviations from the south in 45 ° to the southwest or southeast. More significant deviations can be compensated by a small increase in the surface area of the collector.

2 Methods

2.1 Investigation of air chamber's properties in solar air collectors

Taking into account the most predictable movement of the coolant inside collectors with the movement of the air through air chambers, we shall undertake a study on the efficiency of chamber forms to outline the optimized and the most effective alternative.

The principal condition of providing effective operation of the solar air collector is the maximum coverage of the air chamber walls by the airflow to relieve them from the heat. It can be achieved by creating turbulent flow. The easiest way is to arrange bafflers along the channel, which can provide the turbulence.

In order to get that done, a comprehensive research on the study of the potential of the channels with different types of bafflers.

Prototypes were made of thin-walled cylinder with a smooth inner surface. The 4 section cylinders were secured to the window glass on one level separately from each other, so as not to block the sun's access to the surfaces. Thin-walled aluminum cylindrical tube with a diameter of 70 mm, the wall thickness of 0,1 mm, and 170 mm long section between delimiters, was used as the channel. The tube was covered with CRAFTS SPRAY HighTemperature black paint to improve the perception of solar radiation. Research samples consisted of 4 sections were created for all types of bafflers. All samples were fixed in an identical lighting conditions, the temperature was measured both at the inlet and outlet of the channel with different measurements for each channel in the 20°...30° C.

The second part of the experiment was mathematical modeling of the air passing through the bafflers to visualize the trajectories of the motion of the fluence.

It is flexible enough to check various situations, and it is a good instrument to prepare physical tests, its verification or confirmation.

One of software packages of this kind is SolidWorks, a program complex for the complete 3D modeling with Flow Simulation program unit, which provides opportunities to create the most complex three-dimensional parametric objects and dipping them into certain environment, defining necessary parameters and characteristics, as well as obtaining an animated image of the flow process which is saved as AVI-file.

2.2 Research methodology

Four-sectional samples were fixed to the window glass on one level apart from each other to keep the access to sunlight surfaces.

The principal scheme of the holes in the baffler are shown in Fig. 5. The holes in the bafflers on Schemes 3...9 were made open-ended, changing only the configuration. Openings in the bafflers on Schemes 1...2 were made by fat contour line, then the dimmed plane was bent inwards at an angle of 45°.

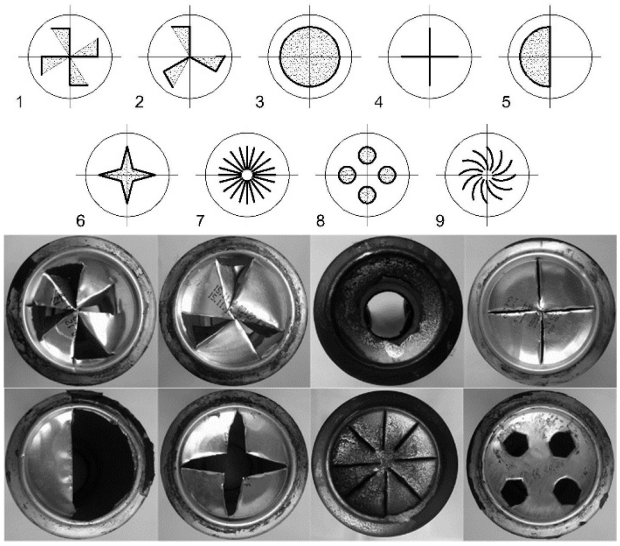

Fig. 5. The principal schemes of the holes in bafflers.

At the junction of sections, each subsequent baffler was turned on an axis at an angle of 90° from the previous for the turbulence of the flow.

Temperature measurements were carried out at the intake of an air flow in the prototype and at the outlet at different lighting levels in the winter and spring periods. Thermo Clock electric thermometer with internal and external (as thermocouple) temperature sensors was used for measurements. Temperature measurements were performed twice:

1st measurement: the temperature at the intake was measured with thermocouple;

2d measurement: the temperature at the intake was measured with the thermometer's internal sensor, and at the outlet it was measured with thermocouple.

Temperature measurements were carried out at different lighting levels, which were metered with luxmeter.

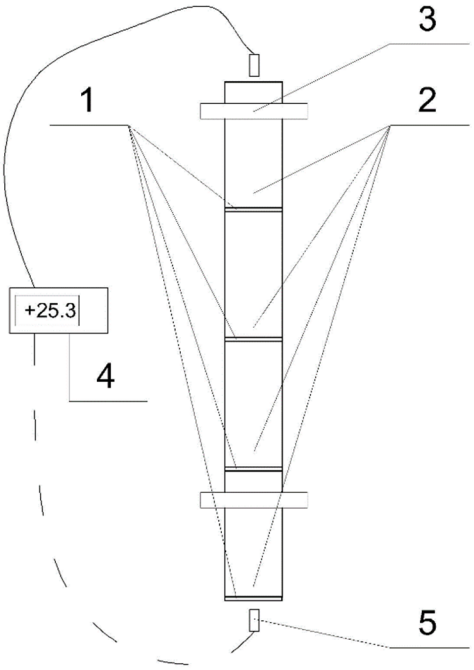

Fig. 6. A scheme for determining the effectiveness of the samples: 1 – baffler; 2 - tube sections; 3 – mounting; 4 – electric thermometer; 5 – thermocouple.

3 Results and discussion

3.1 Efficiency of channels in the field experiment

The results of studies at different levels of illumination are summarized in Table 1.

Table 1. The temperature at the intake and outlet of the samples at different light levels

Row Nr.	**$T_{outside}$**	**Temperature at the outlet of the sample T**							
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	6,0	13,3	12,7	12,5	13	12,8	12,6	13	13,1
2	7,0	15,6	15	14,9	15,4	15,1	15	15	15,4
3	14,5	19,2	16,1	14,5	16,5	14,6	14,5	14,5	17
4	17	43,6	40,1	34	36	38,5	39,5	45,5	38
5	18,6	27,5	28	25	27,3	27,8	26,3	26,8	27,5
6	25,0	46,9	44,4	44,3	45,3	44,8	41,2	50	47,1

Considering that at the time of the study there was a constant cloudiness, the increase in solar radiation led not only to an increase in the outside temperature, but also to an improvement of the heat transfer by the collector elements.

The data of Table 1 are shown on chart (Fig. 7).

With the efficiency of the channel dividers, the difference between the inlet and outlet air flow temperatures is accepted. The results of studies at different levels of illumination are summarized in Table 2.

The results of the experimentation have shown that the most effective was sample Nr. 1, sample Nr. 7 had very

close value to the first one, and samples Nr. 8 and Nr. 2 were in the third place.

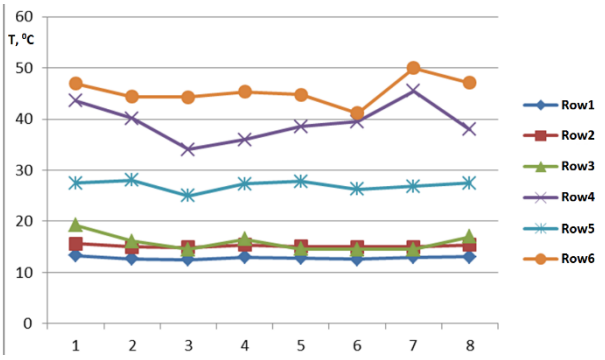

Fig. 7. Temperature distribution in the samples.

Table 2. Effectiveness of chamber bafflers.

Row Nr.	**Difference between inlet and outlet temperatures of air flow**							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	7,3	6,7	6,5	7	6,8	6,6	7	7,1
2	8,6	8	7,9	8,4	8,1	8	8	8,4
3	4,7	1,6	0	2	0,1	0	0	2,5
4	26,6	23,1	17	19	21,5	22,5	28,5	21
5	8,9	9,4	6,4	8,7	9,2	7,7	8,2	8,9
6	21,9	19,4	19,3	20,3	19,8	16,2	25	22,1
Average	**13,0**	**11,37**	**9,52**	**10,9**	**10,92**	**10,17**	**12,78**	**11,67**

We take the effectiveness of the sample Nr. 1 as 100%. Experimental samples in Table 3 are shown in the order of increasing.

Table 3. Experimental samples in the order of increasing of the effectiveness.

Sample Nr.	3	6	4	5	2	8	7	1
Comparative effectiveness	73,21	78,21	83,85	83,97	87,44	89,74	98,33	100

3.2 Channel efficiency in mathematical modeling

To visualize the trajectories of the fluence motion, in the second part of the experiment, Mathematical modeling of air passing through the bafflers was carried out with the aid of SolidWorks program complex with FlowSimulation program unit. The results of modeling are shown on Fig. 8-16.

Mathematical modeling has shown that bafflers of samples Nr. 1, 2 and 7 have the best performance of blowing the chamber walls.

The efficiency of the channel dividers modeled in SolidWorks was determined by the nature of the airflow trajectory after passing them separator.

4 Conclusions

Passing through the channel, the air changes its state. This is due to the differential heating of absorber surface by the sun, and owing to the bafflers that divide the channel into identical pieces. The baffler's shape influences the flow pattern in the air chamber.

The results of the multiple use of air chamber samples of solar collectors with bafflers have shown that samples Nr. 1, 2 and 7 are the best for the use, which we suggest to use for making solar collectors.

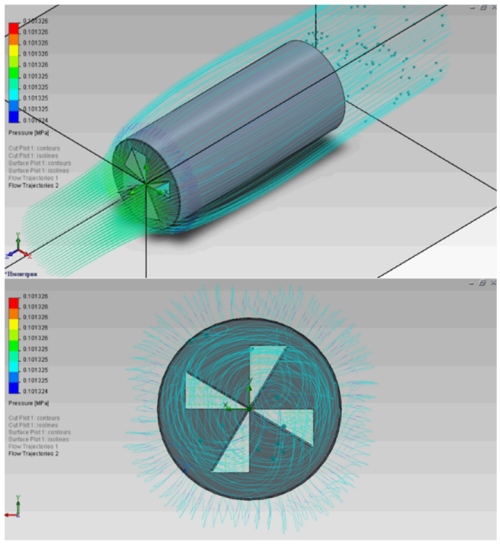

Fig. 8. Mathematical modelling: samples Nr. 1.

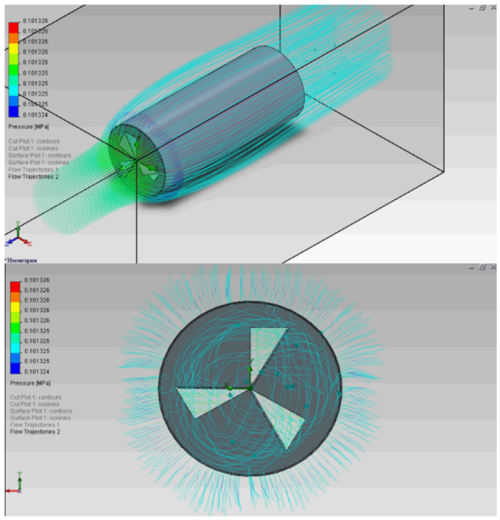

Fig. 9. Mathematical modelling: samples Nr. 2.

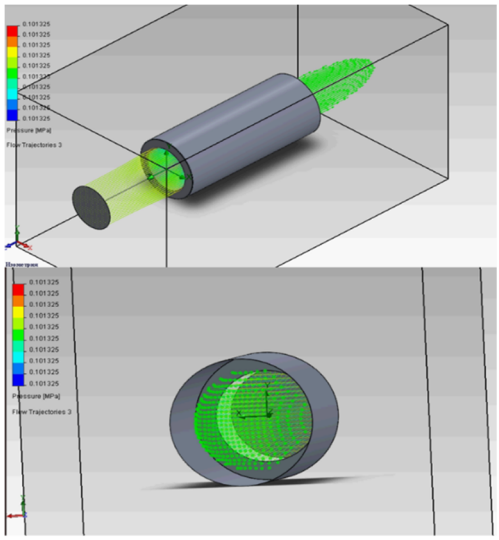

Fig. 10. Mathematical modelling: samples Nr. 3.

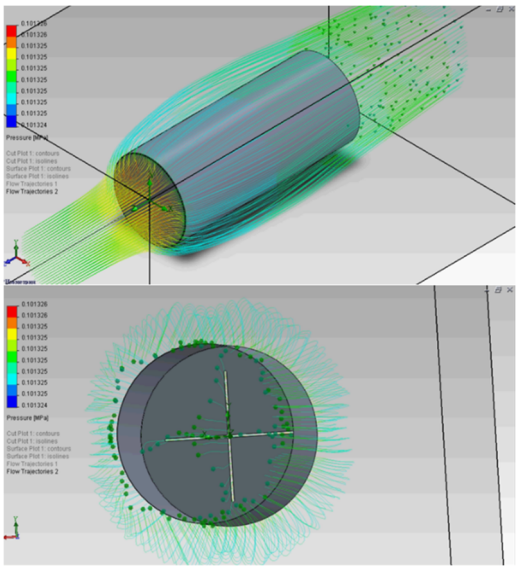

Fig. 11. Mathematical modelling: samples Nr. 4.

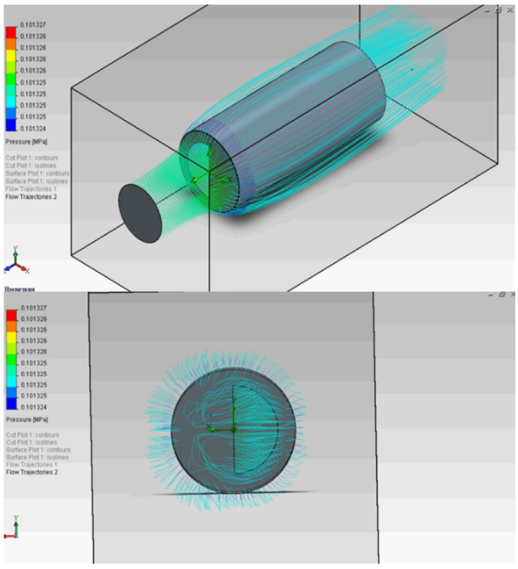

Fig. 12. Mathematical modelling: samples Nr. 5.

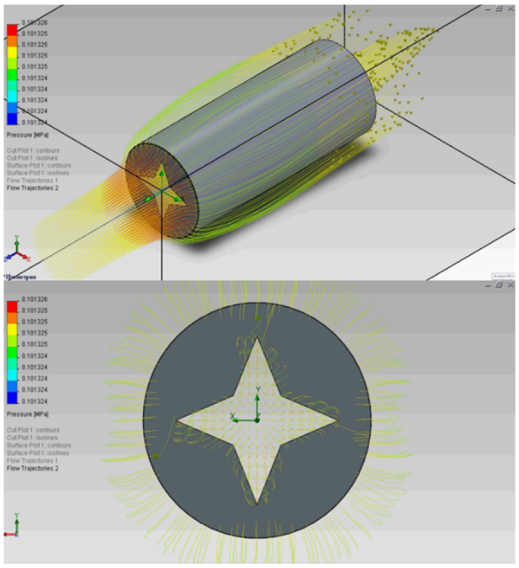

Fig. 13. Mathematical modelling: samples Nr. 6.

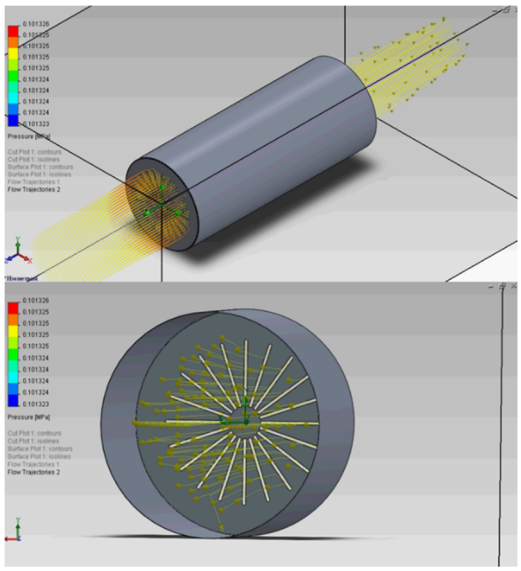

Fig. 14. Mathematical modelling: samples Nr. 7.

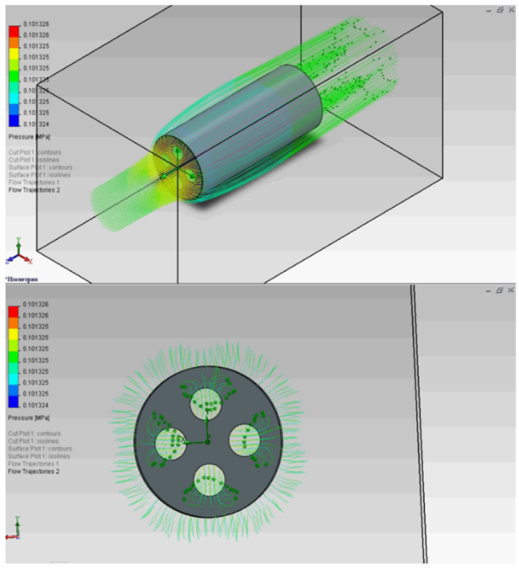

Fig. 15. Mathematical modelling: samples Nr. 8.

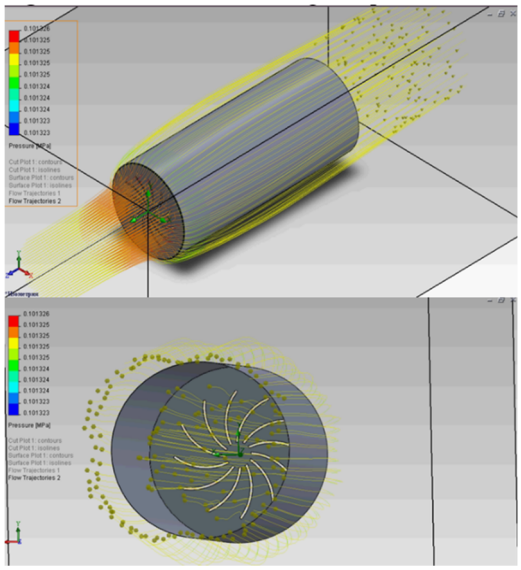

Fig. 16. Mathematical modelling: samples Nr. 9.

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Prospects of environmentally safe use of renewable energy sources in the sustainable tourism development of the Carpathian region of Ukraine

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Abstract. The use of renewable energy in sustainable tourism development of the region is substantiated in the paper. There are three stages in selecting areas for projects on renewable energy sources: selection of the potentially suitable area; consideration of exclusion criteria; detailed assessment of potential areas. The impact factors on spatial constraints and the opportunities for building solar power plants, on the parameters of sustainable tourism development in the Carpathian region were determined. New research findings were obtained, the result of which was the concept and cartographic models of the environmentally safe location of renewable energy objects. New methods and methodological recommendations for the development of renewable energy in the Carpathian region were described as prospective taking into account the constraints on the parameters of environmental safety and tourist use of the territory.

1 Introduction

It is known that in Ukraine, as well as in many countries in the world, there is the need for alternative energy due to the lack of conventional energy sources. At present, it is believed that the use of renewable energy sources is one of the ways to solve this problem. The relevance of the scientific project is apparent and is related to the fact that the world community regards the use of alternative and renewable energy as one of the most promising solutions to the growing problems of energy supply. Solar energy is one of the most promising alternative sources of energy. Considering the dynamics of reducing the cost of electricity, generated by the sun, it is strategically important for Ukraine to develop these directions in the future, especially in such a difficult economic situation.

Many works are devoted to the efficiency and expediency of the use of solar energy [1, 2]. Substantial results are obtained in the Institute of Semiconductors Physics of NAS of Ukraine, in the Kyiv, Odesa, Uzhhorod and Chernivtsi Universities, on some industrial enterprises (“Pillar”, “Quasar”), in other Ukrainian laboratories.

All of them state, that the use of alternative energy sources in Ukraine, mainly solar energy, will undoubtedly bring benefits [3].

The prospects of introducing renewable energy sources should be considered in the light of trends in tourism potential, represented by the number of historical, cultural and natural resources, as well as the level of tourism infrastructure development, which mainly depends on the available number of catering establishments and accommodation.

In general, the current state of analysis and assessment of solar energy sources is considered in the article. The main types of works concerning the natural resources of renewable energy, the scientific achievements related to the use of natural resources for the development of alternative energy, which contain a general and special description of renewable energy resources, ways of their use and evaluation have been singled out and analyzed. The conducted analysis has shown that today more and more authors devote their works to the systematization and improvement of non-traditional energy sources and complex calculation of the options, by means of which energy can be obtained [4-6].

Very often, the necessary data on solar energy are absent, and for this purpose the analytical dependencies are used, which help to solve the set tasks with sufficient accuracy.

Another source of sun radiation of a certain territory is the results of long-term NASA research, including satellite measurement, atmospheric design, and surface studies. In this model, such factors as climatic zones, reflectance, turbidity, precipitation, and aerosols in the atmosphere are used in atmospheric design [7].

Renewable energy sources help to solve the problem of the sustainable development of mankind by reducing air, water and soil pollution, but they can also have an environmental impact.

In addition to favorable climatic characteristics, spatial planning of the area with environmental

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constraints is important, as it can help to avoid the obstacles to planned activities, environmental impact or public dissatisfaction.

2 Problem statement

The purpose of the paper is to substantiate the feasibility of introducing solar energy resources in the Carpathian region and to prove that there are no objective resource obstacles to the development of solar energy in the Carpathian region. Recently, there has been a growing interest in using photovoltaic panels to produce electricity by converting solar energy.

Along with other renewable energy devices, the photovoltaic panels have several advantages, including the simplicity of design and structure, light weight and dimensions, and long life. However, their main disadvantages are their low efficiency, the instability of electricity due to weather conditions and the dependence of output power on the incidence angle of sunlight on the absorbing panel. To use solar installations, it is necessary to have data on the distribution of solar radiation in the area. The administrative Carpathian region includes Ivano-Frankivsk, Lviv, Zakarpattia and Chernivtsi oblasts.

There arises the need to assess the tourist potential of the territories. In this regard, it is necessary to develop a model of tourism organization in the region and identify the territories that require priority concentration of efforts and resources for their development, protected areas and territories where tourism infrastructure is inappropriate [8].

Thus, there is a need to solve the following tasks: to accumulate the data on solar radiation intensity in each tourist region; to process the data and determine probable characteristics of the intensity of solar radiation distribution [9,10].

The introduction of new facilities, including solar power plants, requires a complex of pre-investment research, which should include the environmental impact assessment in addition to assessing the energy potential. The environmental impact assessment is usually carried out in three stages:

1. determination of first-line impacts (screening);
2. development of a complex of mitigation measures;
3. impact significance assessment;
4. decision making.

The notion of "impact significance" is a core concept of the Directive 2011/92/EU "On the assessment of the effects of certain public and private projects on the environment" [11], which was introduced in the Ukrainian legislation in December 2017 by the Law of Ukraine "On Environmental Impact Assessment" (EIA) [12]. Article 3 of the Directive requires that "the environmental impact assessment shall identify, describe and assess in an appropriate manner, in the light of each individual case" [11]. For this reason, it is necessary to justify the impact significance assessment, in particular it is important to establish a transparent methodology that explains the approaches of assessment and its practical application.

The impact significance assessment should not be the exclusive prerogative of professionals: the significance should be determined in such a way as to reflect what is assessed in the environment for the authorities and the public. A common approach used in EIA is a multi-criteria analysis [13]. The multi-criteria comparative analysis, which uses different methods, makes it possible to assess the significance, when it cannot be done using standard absolute methods, and to compare different impacts.

3 Results and discussion

3.1 Method of determining the prospects of the oblasts of the Carpathian region for the implementation of renewable energy sources

The Carpathian region development strategy is the tourism industry. At present, the development of tourism industry requires an ecologically-oriented attitude to natural resources and their use.

Having analyzed the available methods for assessing the tourism potential [14, 15], we propose our own point assessment, based on the integrated ranking of the territories. We propose to introduce an appropriate assessment of tourism potential in accordance with the integrated rating of individual oblasts of the Carpathian region on a scale (1-1.7 – low; 1.8-3.3 – medium; 3.4-5.0 – high) for each area, based on a maximum score of 5 points.

The components of tourism potential are the amount of historical and cultural resources (K*hc*), natural resources (K*n*) and the main components of tourism infrastructure (K*inf*) – accommodation and catering establishments.

Taking into account the number of these units in the oblasts of the region, we introduce a degree of ranking (R) of historical, cultural, natural resources and infrastructure – $R_{Khc}, R_{Kn}, R_{Kinf}$, respectively.

For each of these components, we set the coefficients of significance (S), respectively:

$$S_{Khc} = 0{,}3, S_{Kn} = 0{,}3, S_{Kinf}$$

The integral rank for each region is determined by the sum of the products of the degree of ranking and the importance of each component in Equation 1:

$$I = R_{Khc}{*}S_{Khc} + R_{Kn}{*}S_{Kn} + R_{Kinf}{*}S_{Kinf} \qquad (1)$$

Based on the maximum score of 5 points, we determine the point estimate of the tourist potential by the integrated ranking according to the scale:

- 1-1.7 – low;
- 1.8-3.3 – medium
- 3.4-5.0 – high.

According to the point evaluation of the tourist potential, we have determined the levels of prospects of the oblasts for introducing renewable energy sources in tourist complexes in each of the oblasts of the Carpathian region (Figure 1).

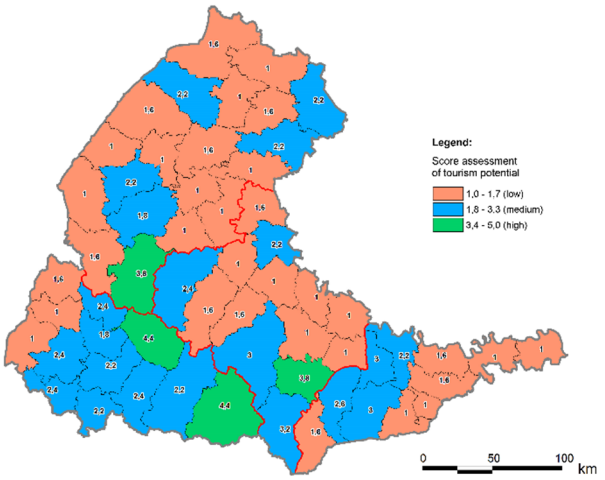

Fig. 1. Estimation of tourist potential by the integrated ranking of individual oblasts of the Carpathian region of Ukraine.

In Ivano-Frankivsk oblast the highest level of prospects can be expected in Kosiv region; medium – in Verkhovyna, Halych, Dolyna, Nadvina, Yaremche regions, Ivano-Frankivsk; low – in Bohorodchany, Horodenka, Kalush, Kolomyia, Rohatyn, Rozhniativ, Sniatyn, Tysmenytsia, Tlumach regions.

In the case of Lviv oblast, the highest level of prospects can be expected in Skole region and the outskirts of Lviv; medium – in Brody, Drohobych, Zhovkva, Zolochiv, Sambir regions; low – in Buh, Horodok, Zhydachiv, Kamianka-Buzka, Mykolaiv, Mostysky, Peremyshliany, Pustomytiv, Radekhiv, Sokal, Starosambir, Stryi, Turkiv and Yavoriv regions.

In Zakarpattia oblast the highest level of prospects is in Mizhhirria and Rakhiv regions; medium – in Berehovo, Vynohradiv, Volovetsk, Irshava, Mukachevo, Svaliava, Tiachiv, Khust regions; low – in Velyki Berezniany, Perechyn and Uzhhorod regions.

In Chernivtsi oblast the highest level of prospects are on the outskirts of Chernivtsi; medium – in Vyzhnytsia, Zastavna, Kitsman, Storozhynets regions; low – in Hertsaiv, Hlybochytsia, Kelmintsi, Novoselytsia, Putyvl, Sokyriany and Khotyn regions.

3.2 Method of determining the prospects of the oblasts of the Carpathian region for the implementation of renewable energy sources

Having identified which areas are promising in terms of tourism industry development, we can envisage the appropriate scenarios for the introduction of renewable energy sources, attracting internal and external investments in tourism activities related to the sphere of the economic complex of the region. The regional average annual values of the total solar radiation within the whole Carpathian region on the horizontal (underlying) surface are presented on the Map Info map, that we developed in GIS, in Figure 2, containing 10 color gradations. The results indicate a gradual decrease in the quantitative indicators in the direction of the south-east-northwest.

The efficiency of light-absorbing panels operation in the Carpathian region has been studied on the basis of the Ivano-Frankivsk National Technical University of Oil and Gas since April 2015. Daily measurements of electricity produced and meteorological indices are carried out.

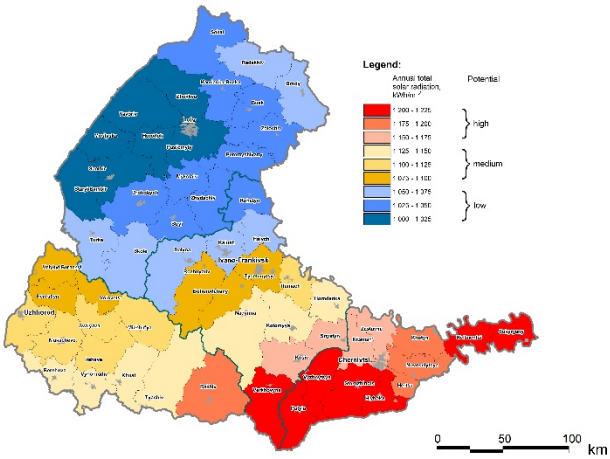

Fig. 2. Annual total solar radiation in the Carpathian region of Ukraine.

The experimental study has been conducted; the obtained results have been statistically processed. The functional dependence of generating electricity on meteorological parameters has been identified, namely, cloudiness, probability of precipitation, air temperature, atmospheric pressure, humidity and wind speed.

According to the results, the amount of obtained energy substantially depends on the indexes of cloudiness (Figure 3), humidity (Figure 4), and air temperature (Figure 5).

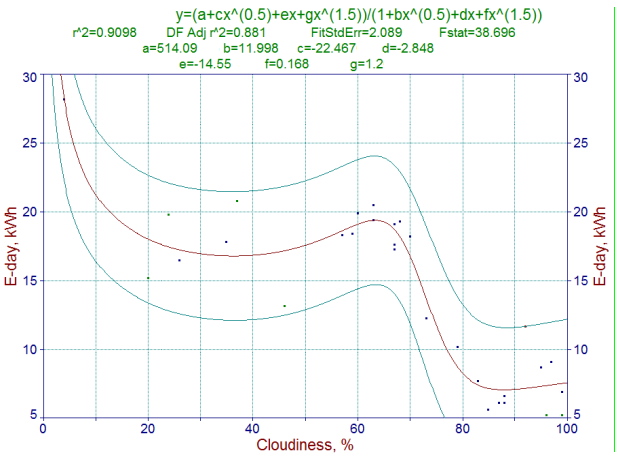

Fig. 3. Functional dependency of electricity generation by the photovoltaic panels on the level of cloudiness in Ivano-Frankivsk.

Functional dependencies were established by processing long-term observation data using TableCurve 2D software. The program uses the basic criteria of statistics: the sum of squares of the mean, sum of squares of errors (residuals), degree of freedom calculated depending on the number of model parameters, standard error, coefficient of determination (r^2), coefficient of determination adjusted for the degree of freedom (DF r^2), and F-statistics (Fisher test).

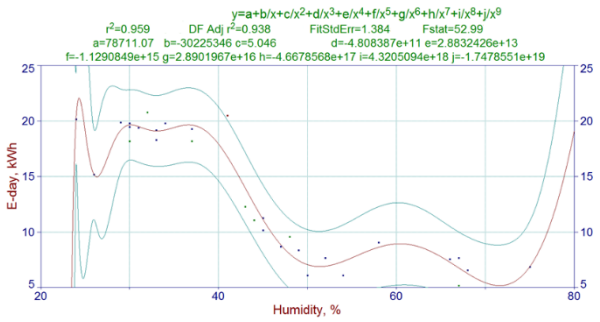

Fig. 4. Functional dependency of electricity generation by the photovoltaic panels on the level of humidity in Ivano-Frankivsk.

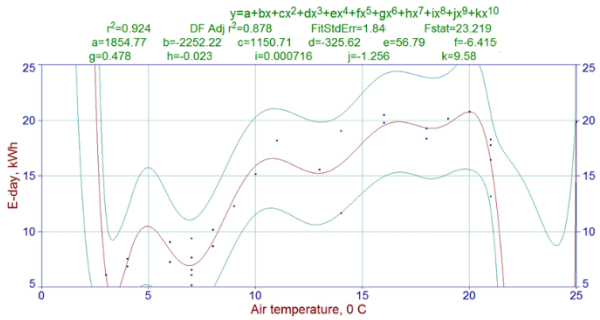

Fig. 5. Functional dependency of electricity generation by the photovoltaic panels on the air temperature in Ivano-Frankivsk.

The values of the coefficient of determination were estimated using the F-distribution quantile tables and the tables of values of coefficients. The critical values of the Fisher test were defined according to standard tables. The hypothesis (existence of a close dependence) was rejected if the value found in the table (Fstatt) was greater than the calculated (Fstatm), and was accepted as the one that was confirmed if Fstatt <Fstatm. In three cases (Figures 3, 4, 5), the hypothesis was confirmed, provided that the significance level was accepted at 1%.

However, there is no direct correlation between the indices of atmospheric pressure and wind speed. In two cases (Figures 6, 7) the hypothesis was rejected, provided that the significance level was accepted at the level of 1%. The critical values of the Fisher test corresponded to standard tables. The hypothesis (existence of close dependence) was rejected because the value found in the table (Fstatt) was larger than the calculated one (Fstatm).

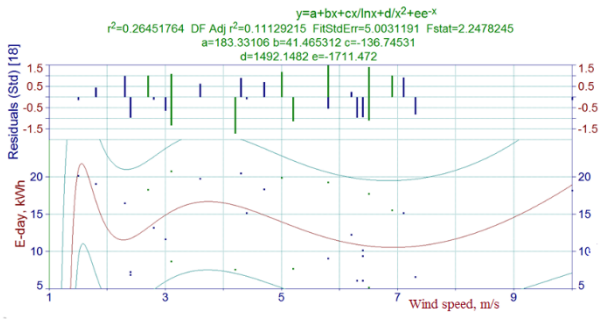

Fig. 6. Results of processing the experimental data of measurements of electricity production by photovoltaic panels and wind speed in Ivano-Frankivsk.

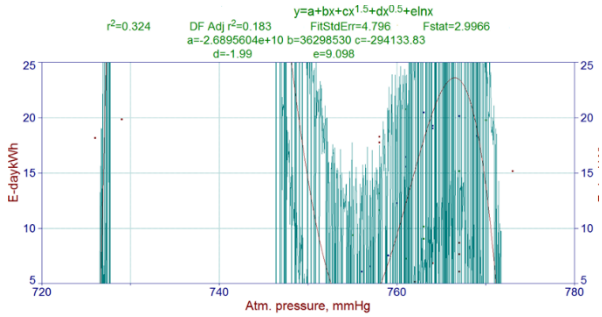

Fig. 7. Results of processing the experimental data of measurements of electricity production by photovoltaic panels and atmospheric pressure in Ivano-Frankivsk.

Therefore, based on the obtained experimental data and statistical meteorological data, the dependency curves of electricity production with the help of a light-absorbing panel on weather conditions were developed, which made it possible to perform forecast calculations.

The scientific novelty of the performed research is that we obtained significant functional dependencies of electricity production by means of a light-absorbing panel on the air temperature, cloudiness, relative humidity for local conditions of Ivano-Frankivsk oblast.

3.3 Method for environmental impact significance assessment of renewable energy

The suggested method for environmental impact significance assessment is based on the requirements of the national legislation for the components of the Environmental Impact Assessment report [12], the recommendations of the EU guidelines on Environmental Impact Assessment [13, 16], national guidelines on the implementation of the Strategic Environmental Assessment (SEA) [17], data of the Strategic Environmental Review conducted by Ukraine Sustainable Energy Lending Facility (USELF) [18]. In particular, the SEA guidelines recommend using a methodological approach to significance assessment that is based on the evaluation of all identified impacts by uniform qualitative and quantitative criteria that reflect the magnitude of impact (including intensity, spatial and temporal coverage, reversibility, probability of occurrence) sensitivity of the recipient.

The proposed method concerns the impact of the significance assessment of renewable energy, in particular solar power plants, on the environment and is carried out after screening and mitigation measures.

Due to the fact that many factors impacting the natural and socioeconomic environment cannot be quantified, a rating method of impact assessment is proposed, which allows comparing different types of impacts using the matrix method.

Impact significance is assessed in points. The methodology is based on the four specified parameters of impact: probability, extension, duration, and intensity.

The significance assessment enables the business entity to indicate the need for additional mitigation measures as well as to inform the competent authority, local authority and the public about the most significant

adverse impacts. The results of such assessment will be well understood by all stakeholders as they imply three levels of significance – low, medium and high impact.

The assessment of impacts on the natural environment is carried out according to individual components: climate, atmospheric air, geological environment, soil, water; flora, fauna and biodiversity [19]. The impact assessment on the socioeconomic environment is carried out based on the following components: landscape, human health, socioeconomic situation (employment, communal infrastructure, transport, resources use), historical and cultural heritage.

For the natural environment, zero impact is not taken into account, as any activity will have an effect on the natural environment. Zero impact will only be in the absence of planned activities. The significance rank for each parameter is estimated according to the criteria suggested in Tables 1-4.

Table 1. Criteria for the significance of the impact probability on the natural environment.

Gradation	Impact probability, %	Point
Very low probability	< 10	1
Low probability	10-50	2
Moderate probability	50-90	3
High probability	> 90	4

Table 2. Criteria for the significance of impact spread on the natural environment.

Gradation	Impact spread	Point
Site	Facies, tracts / < 1 km^2	1
Local	Groups of tracts, terrain / 1-10 km^2	2
Landscape	Landscape / 10-100 km^2	3
Regional	Landscape districts, provinces / > 100 km^2	4

Table 3. Criteria for the significance of impact duration on the natural environment.

Gradation	Impact duration	Point
Short-term	Up to 3 months	1
Medium-term	From 3 months to 1 year / Stage of construction	2
Long-term	From 1 to 3 years / Construction	3
Very long-term / (permanent)	More than 3 years / Operation	4

To assess the whole set of consequences of the planned activity on the social and economic conditions, a 5-level ranking with 0 to 4 points is proposed, with a negative and positive sign, both negative and positive factors of impact are ranked.

Each ranking of impact on the components of the socioeconomic environment is determined by the relevant criteria in Tables 5-8.

The impact significance is an integrated (integral) estimate. Impact significance assessment is carried out in several stages.

Stage 1. To determine the impact significance on the individual environmental components, it is necessary to use Tables 1-8 with the criteria of impact and Equation 2.

The impact significance on *i*-th environmental component is determined as follows:

$$Q_i = Q_i^p \cdot Q_i^s \cdot Q_i^t \cdot Q_i^j \quad (2)$$

Q_i^p – a point of impact probability on *i*-th environmental component;
Q_i^s – a point of impact spread on *i*-th environmental component;
Q_i^t – a point of impact duration on *i*-th environmental component;
Q_i^j – a point of impact intensity on *i*-th environmental component.

Table 4. Criteria for the significance of impact intensity on the natural environment.

Gradation	Impact intensity	Point
No intensity	Changes in the natural environment do not exceed the existing limits of natural variability / Less than 10% of the object changes	1
Low intensity	Changes in the natural environment go beyond the limits of natural variability, the natural environment is completely self-healing / 10-50% of the object changes	2
Moderate intensity	Changes in the natural environment, which exceed the limits of natural variability, violate the individual components of the natural environment. The natural environment retains the ability to self-healing / 50-90% of the object changes	3
High intensity	Changes in the natural environment result in significant damage to the components of the environment or ecosystems. Separate components of the natural environment lose their ability to self-healing / More than 90% of the object changes	4

Table 5. Criteria for the significance of impact probability on the socioeconomic environment.

Gradation	Impact probability, %	Point
Zero impact	no impact	0
Very low probability	< 10	1
Low probability	10-50	2
Moderate probability	50-90	3
High probability	> 90	4

Table 6. Criteria for the significance of impact spread on the socioeconomic environment.

Gradation	Impact extension	Point
Zero impact	no impact	0
Site	Site of the object	1
Local	Adjacent settlements	2
District	One or more administrative districts	3
Regional	Region	4

Table 7. Criteria for the significance of the impact duration on the socioeconomic environment.

Gradation	Impact duration	Point
Zero impact	no impact	0
Short-term	Up to 3 months	1
Medium-term	From 3 months to 1 year / Stage of construction	2
Long-term	From 1 to 3 years / Construction	3
Very long-term / (permanent)	More than 3 years / Operation	4

Table 8. Criteria for the significance of impact intensity on the socioeconomic environment.

Gradation	Impact intensity	Point
Zero impact	no impact	0
Very low intensity	Positive and negative deviations in the socioeconomic environment correspond to the existing fluctuations of the variability of this indicator before the project implementation / Less than 10% of the object changes	1
Low intensity	Positive and negative deviations in the socioeconomic environment outweigh the existing trends in the changing living conditions in settlements / 10-50% of the object changes	2
Moderate intensity	Positive and negative deviations in the socioeconomic environment exceed the existing conditions of the medium level / 50-90% of the object changes	3
High intensity	Positive and negative deviations in the socioeconomic environment outweigh the existing conditions of the medium-regional or inter-regional level / More than 90% of the object changes	4

Stage 2. The level of significance is determined by the interval of values depending on the grade, obtained in the calculation, as shown in Table 9.

Table 9. Levels of impact significance on the environment.

Point	Impact significance
from +1 to +16	Low positive impact
from +17 to +81	Moderate positive impact
from +82 to +256	High positive impact
0	no impact
from -1 to -16	Low negative impact
from –17 to –81	Moderate negative impact
from –82 to –256	High negative impact

The significances are the same for different environmental components and can be compared with the identified component that is most affected.

The significance levels are determined for all environmental components. If the impact significance, determined for a particular environmental component (atmospheric air, fauna, etc.), is the only one, it is directly used to assess the resulting significance of the impact. However, in practice, one environmental component can be influenced by different sources (activities). Then the integrated (average) assessment of the significance of the impact on *i*-th environmental component will be the following:

$$Q_{int\,egr} = \frac{\sum_{k=1}^{n} Q_{ki}}{n} \qquad (3)$$

where Q_{ki} – an integrated point of *k*-th impact (type of activity) on the *i*-th environmental component;
n – the number of impacts (activities) on the *i*-th component of the environment.

It is expedient to analyze the impacts on certain components of both natural and socioeconomic environments from different sources with the help of estimating matrices based on the matrix of Leopold. The integral (average) estimates for a particular component of the environment are used to determine the significance of the impact.

Conclusions

We use the estimates of tourist potential based on the integrated ranking of individual areas. As a result, it is possible to envisage the appropriate scenarios for the introduction of renewable energy sources, attraction of internal and external investments in tourist activities related to the field of economic complex.

The developed map of quantitative indicators of solar energy potential for the facilities providing renewable energy in the Carpathian region of Ukraine shows the feasibility of introducing the opportunities for using solar energy in the Carpathian region. The results of experiments showed the dependence of energy generation by photovoltaic panels on the meteorological elements of weather conditions, in particular cloudiness, humidity and air temperature. At the same time, it has no direct dependence on the atmospheric pressure and wind speed.

The method for environmental impact significance assessment of renewable energy has been proposed. It is performed after screening and mitigation measures. Due to the fact that the impact of many factors on the natural and socioeconomic environmental components cannot be quantified, a rating method of impact assessment has been proposed, which allows comparing different types of impacts using the matrix method. The methodology is based on the four specified parameters of impact: probability, spread, duration and intensity.

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The fuzzy logic controllers synthesis method in the vector control system of the wind turbine doubly-fed induction generator

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Abstract. The article is devoted to the improvement of control systems for wind turbines by developing fuzzy controllers with higher transient characteristics and low computational costs of identification in comparison with the applied PI controllers. Based on the self-organization method, a fuzzy speed controller of the doubly-fed induction generator (DFIG) of a wind turbine was synthesized, which uses a zero-order Sugeno fuzzy inference system and is made in the form of a block-oriented Wiener model. This regulator is an element of the vector control system of the transistor converter on the rotor side. The results of simulation modeling of the fuzzy controller showed that it provides a lower transition time compared to the PI controller, by 53.59% during acceleration and by 79.76% during braking, and 23.81% less error speed deviations from the reference signal. Such indicators can minimize losses while maintaining the maximum output power point of the power plant. The implementation of the developed system on wind turbines contributes to increasing the efficiency of wind farms, reducing the cost of electricity production, reducing the payback period of equipment, and the sustainable development of alternative energy in general.

Introduction

The sharp increase in the number of wind farms integrated into existing power systems has predetermined the need to increase the volume of electricity generation while reducing the reserves of non-renewable fuel and energy resources, as well as the rapid development of the elemental base of power electronics devices used in wind power converters. As a result, in Europe, the share of wind energy in the structure of electricity production approaches 40%, and in some countries, it exceeds this indicator [1].

The main element of a wind farm is a wind turbine, which converts the kinetic energy of the wind flow into electrical energy [2]. For horizontal axis wind turbines, it was established [2, 3] that the dependence of the output power of the turbine on the angular frequency of generator shaft rotation is unimodal, and its extremum point drifts with changing wind speed. Thus, to ensure maximum efficiency of electricity generation, it is necessary to be able to adjust the rotation speed of the generator shaft. For this purpose, asynchronous generators made according to the scheme of the doubly-fed induction generator (DFIG) [4, 5] are used. The angular frequency of generator rotation, depending on the design, is determined by the difference or the sum of the voltage frequencies supplied to the stator and rotor windings.

At the same time, when finding the extremum point, it is necessary to provide stabilization of the rotation speed. Given that the wind speed can change quite often and sometimes in a wide range, therefore, high-quality regulation and stabilization of rotation speed, which provides a short transient time, the absence of overshoot and errors in static, will increase the efficiency of electricity production, as a result of reducing losses while ensuring maximum output power of the energy unit. This will contribute to the broader introduction of wind turbines in existing electric networks due to the reduction in the cost of generating electricity and reducing the payback period for the construction of new wind farms. A constant increase in the share of wind energy in the structure of global electricity production will ensure the sustainable development of alternative energy in general.

To regulate the rotation speed of DFIG, the vector control method of the voltage frequency, which is supplied to the rotor winding [4–13].

In such systems, the PI controllers of speed and current are traditionally used [6–13]. Improving the quality of regulation can be achieved using, for example, ARMABIS structures [14] or control systems with a predictive model based on orthogonal functions [15–17], which have high transient rates. More common is the approach that involves the replacement of classical PI controllers with fuzzy logic controllers [18–23].

However, the synthesis of such controllers is a resource-intensive process that requires significant time, material and computational costs and involves the implementation of two stages.

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First, by a preliminary expert assessment, fuzzy production rules of the controller's knowledge base are formed, the type of the fuzzy inference system, and the initial parameters of the controller are selected.

After that, structural and parametric identification of the fuzzy controller is carried out experimentally on a real object or a simulation model. Due to high computational loads, they are limited only by parametric identification.

Thus, the development of a method for the synthesis of fuzzy controllers in the vector control system of the wind turbine doubly-fed induction generator with low computational costs is an urgent task.

1 The characteristic of the control object

The structure of the control system for a wind turbine (fig. 1) [6] was adopted as a control object. It consists of an asynchronous generator made according to the scheme of a doubly-fed induction generator (DFIG), the stator of which is connected to the electric power grid through a transformer, and the rotor receives power from the stator circuit through the converter. The converter consists of two bridge circuits with transistor switches with an intermediate DC-link. The speed control of the motor shaft is directly controlled by the converter located on the rotor side. Therefore its control system will be considered in this work.

The control system includes pulse width modulation unit (PWM), coordinate converters dq → ABC and ABC → dq, which implement the direct and inverse Park-Gorev transform, phase-locked loop (PLL), fixing the position of the spatial vector, reactive power calculation unit in the stator circuit (Q_c calc) and four fuzzy logic controllers – angular speed (ω_m), stator reactive power (Q_s), active and reactive components of the rotor current (I_{dr}, I_{qr}).

The analytical model of the system used in the simulation is considered in detail in [4, 6, 7].

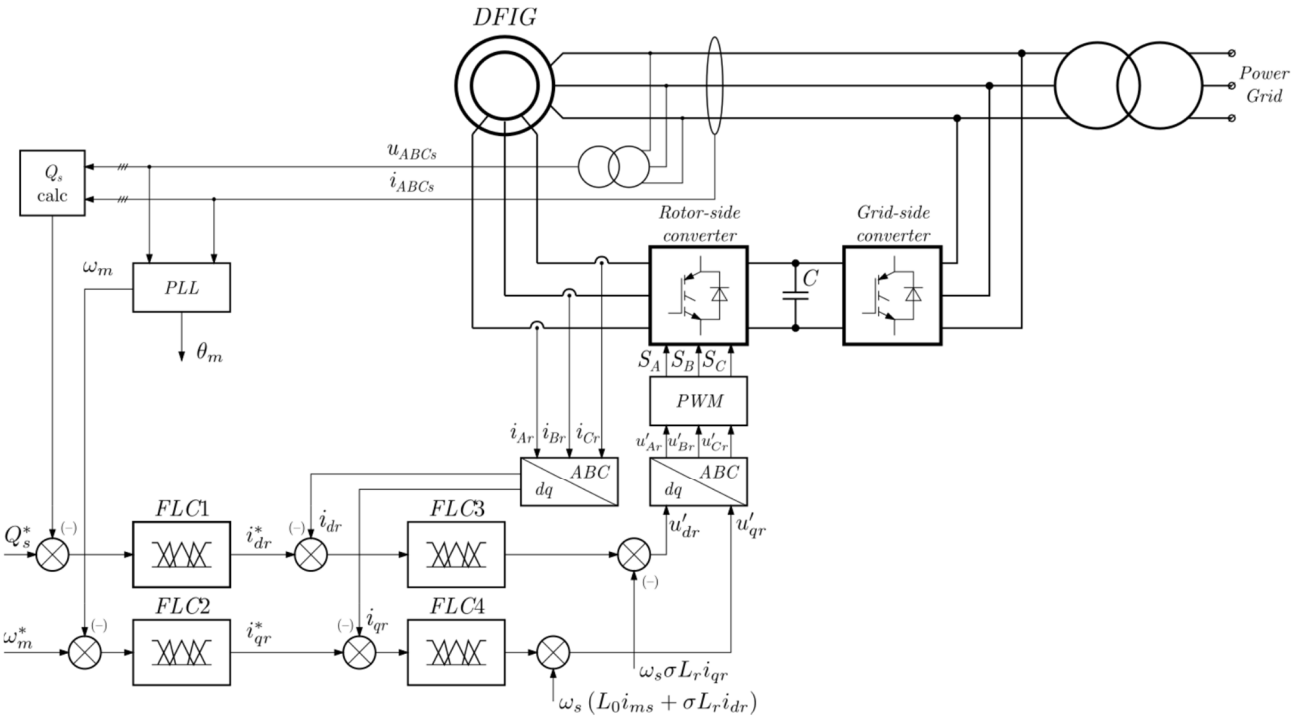

Fig. 1. The block diagram of the vector control system of the rotor-side converter of the wind turbine doubly-fed induction generator.

2 Synthesis of a fuzzy logic controller of the angular frequency of a wind turbine rotation based on a self-organization algorithm

In order to simplify, we represent the speed control system of an asynchronous generator in the form of a closed-loop control system with a fuzzy logic controller (FLC) and a wind turbine fig. 2.

The controller is made in the form of a Wiener structure and consists of a linear time-invariant block (LTI) and a fuzzy inference system unit (FIS) [24].

The controller should provide a minimum deviation of the real angular frequency of the wind turbine generator rotation ω_m from speed reference ω_m^*, which is formed by an extreme regulation system. In this case, it is necessary to maintain acceptable quality indicators of the transition process.

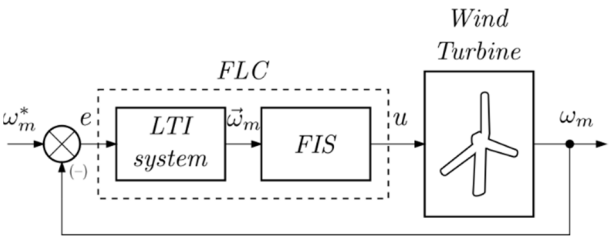

Fig. 2. The control system structure of a wind turbine with a fuzzy logic speed controller.

It is advisable to evaluate the efficiency of the controller by the mean-square error of a system of the form:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(\omega_m - \omega_m^*)^2. \quad (1)$$

To form a set of fuzzy rules of FIS, it is necessary to have a model that approximates the dynamics of a wind turbine, a set of laws for changing input influences ω_m^*, by which the quality of the control system with a fuzzy controller is evaluated, and the structure of the LTI block (in the simplest case, LTI should provide for the input of the FIS control error *e* and its derivative *de/dt* [24, 30]).

Discrete fuzzy controller is shown in fig. 3.

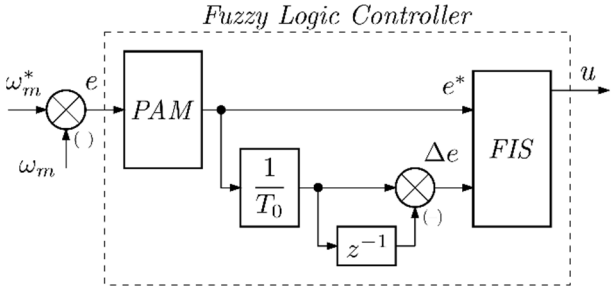

Fig. 3. The block diagram of a shaft speed fuzzy controller of the wind turbine doubly-fed induction generator.

The controller structure includes the PAM block – pulse-amplitude modulator with a zero-order lock, described by the equation: $e^*(t) = e(t_k)$ with $t \in [t_k,\ t_{k+1}]$, where $t_k = k \cdot T_0$ – is the discrete sampling time, k = 0, 1, 2, ... – are the discrete-time samples, T_0 = 0,1 – is the sampling period.

The fuzzy inference block of the FIS controller implements the zero-order Sugeno fuzzy inference algorithm [24–27, 30].

Let's apply the complementing-optimizing self-organization algorithm of a fuzzy logic inference system [24, 28, 29]. Reduced computational costs characterize this algorithm compared with the known algorithms for building up fuzzy neural networks.

Let's describe the essence of the algorithm concerning the task of constructing a fuzzy speed controller for the rotation of an electric generator of a wind turbine.

The FIS block implements the static nonlinearity of the block-oriented Wiener system of the form:

$$u = \varphi(\vec{\omega}_m), \quad (2)$$

which should minimize the functional $MSE = G(\varphi(\vec{\omega}_m))$, characterizing the quality of the control system according to (1).

Let's suppose that in (2) there is a priori information written as a set *N* fuzzy production rules of the form: Π_k: **IF** ω_1 is A_{k1} **AND** ω_2 is A_{k2} **AND** … **AND** ω_n is A_{kn}, **THEN** $u = u_k$, where k = 1, 2, ..., N – is the knowledge base rule number, ω_j (j = 1, 2, ..., n) – are the vector components $\vec{\omega}_m$, A_{rj} – are the fuzzy numbers with membership functions $\mu_{rj}(\omega_j)$.

A priori information may not be available (i.e. N = 0).

Using simulation, the values of functional $MSE = MSE(\varphi(\vec{\omega}_m))$ with the current form of dependency $\omega_m = \varphi(\vec{\omega}_m)$ are determined.

The algorithm assumes the following sequence of actions.

Step 0 (preliminary). The parameter ε is defined, which determines the accuracy of minimizing the error function of the form (1).

The expert method determines the a priori rule base of the fuzzy logic controller, consisting of *N* fuzzy production rules The current number of rules in the database $N_i = N$ is set.

Step 1. If the generated knowledge base is empty go to step 2, otherwise, using the zero-order Sugeno fuzzy inference algorithm and existing production rules, the estimate $\varphi_N(\vec{\omega}_m)$ is determined [24, 30]:

$$\varphi_N(\vec{\omega}_m) = \frac{\sum_{k=1}^{N} u_k \cdot \xi_k(\vec{\omega}_m)}{\sum_{k=1}^{N} \xi_k(\vec{\omega}_m)}, \quad (3)$$

where $\xi_k(\vec{\omega}_m) = \mu_{k1}(\omega_1) \times \mu_{k2}(\omega_2) \times \ldots \times \mu_{kn}(\omega_n)$ – is the truth degree of the premises of the *k*-th rule.

According to the estimate (3), the value of the functional MSE_N is determined using simulation (see formula (1)).

Step 2. The knowledge base is replenished with a rule of the form: Π_{N+1}: **IF** ω_1 is $A_{(N+1)1}$ **AND** ω_2 is $A_{(N+1)2}$ **AND** … ω_n **AND** $A_{(N+1)n}$, **THEN** $u = u_{N+1}$, where $A_{(N+1)j}$ – are the fuzzy numbers with triangular membership functions [24, 30]:

$$\mu_{(N+1)j}(\omega_j) = \begin{cases} 1 - \dfrac{|\omega_j - \gamma_{(N+1)j}|}{\psi_{(N+1)j}}, & \text{IF } |\omega_j - \gamma_{(N+1)j}| \le \psi_{(N+1)j}, \\ 0, & \text{IF } |\omega_j - \gamma_{(N+1)j}| > \psi_{(N+1)j}, \end{cases} \quad (4)$$

where $\gamma_{(N+1)j}$ – are the fuzzy number centers $A_{(N+1)j}$.

The formula (3) determines the estimate $\varphi_{N+1}(\vec{\omega}_m, \gamma_{(N+1),1}, \ldots, \gamma_{(N+1),n}, u_{N+1}, \psi_{(N+1),1}, \ldots, \psi_{(N+1)n})$. Parameter identification $\gamma_{(N+1)1}, \ldots, \gamma_{(N+1)n}, u_{N+1}, \psi_{(N+1)1}, \ldots, \psi_{(N+1)n}$ by optimizing the function: $MSE_{N+1} = MSE(\eta_{N+1}(\vec{\omega}_m, \gamma_{(N+1)1}, \ldots, \gamma_{(N+1),n}, u_{N+1}, \psi_{(N+1),1}, \ldots, \psi_{(N+1)n}))$ by the specified parameters is performed [24, 30].

Step 3. Check inequality:

$$MSE_N - MSE_{N+1} \le \varepsilon, \quad (5)$$

where $MSE_N = MSE(\varphi_N(\vec{\omega}_m))$,
$MSE_{N+1} = MSE(\varphi_{N+1}(\vec{\omega}_m))$.

The value of *N* is incremented: $N = N + 1$.

If inequality (5) is not satisfied, go to step 2, otherwise, go to step 4.

Step 4. The knowledge base of the fuzzy logic controller is considered to be formed. The result is a knowledge base consisting of *m* production rules, while the value of the function is MSE_N.

The FIS knowledge base of the fuzzy speed controller of an electric wind turbine, obtained by an expert method, is presented in Table 1.

The membership functions of the fuzzy variables N, Z, and P have the form shown in fig. 4.

The mean-square error (1) is considered as an indicator of the quality of the control system when a single

step action is applied to the input of the system $\omega_m^* = 1_0(t)$.

Table 1. A set of fuzzy rules of FIS

*R*1:	**IF**	e*	is	P,	**THEN**	$u = 1$
*R*2:	**IF**	e*	is	N,	**THEN**	$u = -1$
*R*3:	**IF**	Δe	is	P,	**THEN**	$u = 1$
*R*4:	**IF**	Δe	is	T,	**THEN**	$u = -1$
*R*5:	**IF**	e*	is	Z,	**AND** Δe is Z, **THEN**	$u = 0$

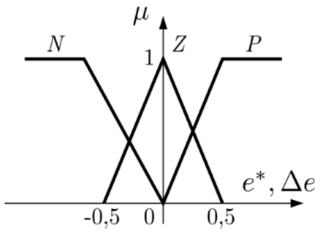

Fig. 4. Membership functions of fuzzy variables N, Z and P.

Preliminary modeling of a wind turbine control system, in which a fuzzy logic controller is defined by the five production rules described above, revealed the following result: *MSE* = 0,00451.

Then the synthesis in accordance with the described algorithm was performed. A priori knowledge base corresponds to the Table. 1. The value of the accuracy parameter is ε = 0,01.

The added rules are of the form:

$$\text{IF} \quad e^* \text{ is } A_{ek} \text{ AND IF} \quad \Delta e \text{ is } A_{\Delta ek}, \text{ THEN } u = u_k.$$

The following parameters of the added rules were optimized: membership function centers γ_{ek}, $\gamma_{\Delta ek}$; consequences of the rules u_k; total dispersion ψ_k for both membership functions. As a result of the self-organization algorithm, the following results were obtained: total generated rules considering a priori $N = 8$; the value of the mean-square error decreased to *MSE* = 0,00286, which is 1,58 times smaller than the original structure of the controller.

3 Implementation of a fuzzy logic controller of the angular rotation frequency of a wind generator based on a self-organization algorithm

To conduct a computational experiment to assess the quality of the fuzzy speed controller of DFIG, synthesized by the proposed method, a simulation model of the system was developed in the MATLAB/Simulink/Simscape Power Systems software package. The dynamic model of an electric machine is based on the analytical equations presented in [4, 6]. A generator with a power of 2 MW was adopted as an object. The equivalent circuit of the object parameters was taken from [4, P. 181].

During the experiment, the speed reference signal changed according to the following law: when starting the machine $\omega_m^* = 1\ p.u.$, which corresponds to the rated rotation speed at the rated wind speed; at 3 seconds, the reference signal step to $\omega_m^* = 0{,}9\ p.u.$, and at 6 seconds it steps up to $\omega_m^* = 0{,}95 p.u.$

Fig. 5 shows the speed transients in control systems using PI and fuzzy logic controllers.

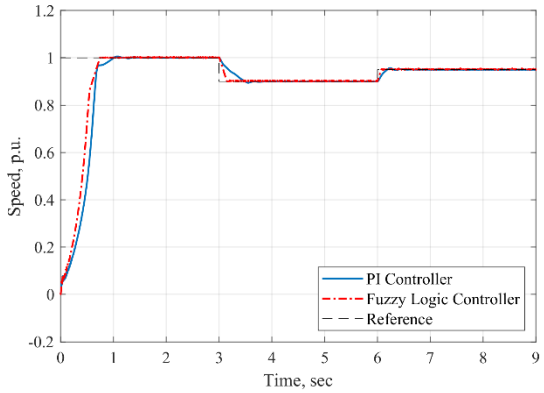

Fig. 5. Speed transients when using a PI controller and a fuzzy logic controller.

The analysis of transient processes in speed shows that the application of the developed fuzzy controller provides the best quality of the control system of wind turbine converter in dynamic modes. Thus, the transient time during the acceleration of the asynchronous dual-supply generator for the fuzzy controller was 0.71 s, which is 53.59% less than the PI controller, for which this indicator is 1.53 s. When reduced by 3 s, the speed reference signal reaches 0.9 for the compared fuzzy and PI controllers, and the speed was 0.17 s and 0.84 s, respectively. That is, when the machine brakes, the transition time in the control system with a fuzzy controller is 79.76% less. Let's also note that when applying the PI controller, overshoot is observed. However, this indicator does not exceed 1%, which is acceptable. There is no error in the statics of both controllers. As a result of the deviation of the object output from the reference signal, $MSE_{FLC} = 0{,}0016$ and $MSE_{PI} = 0{,}0021$ were made. A 23.81% error reduction indicates the best quality of the proposed zero-order Sugeno fuzzy controller.

Additionally, transient graphs of the main state variables of the DFIG were obtained (fig. 6–15).

Transients in the electromagnetic torque are shown in fig. 6 and fig. 7.

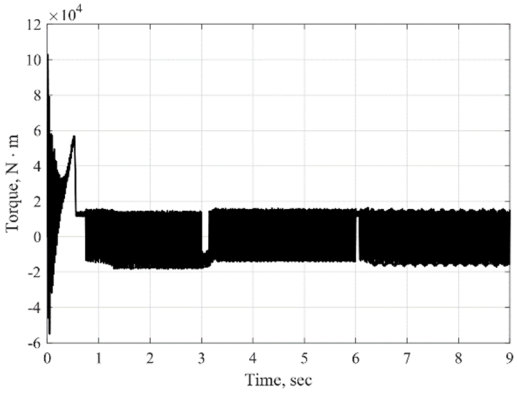

Fig. 6. The torque transient when using the PI speed controller.

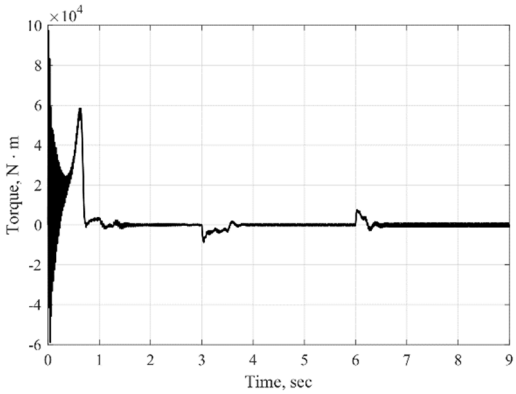

Fig. 7. The torque transient when using a fuzzy logic controller.

The peak value of the electromagnetic torque is 103,445 N·m during the acceleration of the motor with a PI speed controller. The use of a fuzzy regulator leads to a decrease in the maximum value of the torque to 97938 N·m, which is 5.32% less. At the same time, when the angular velocity is stabilized in a system with a PI controller, torque fluctuations with an amplitude of 18234 N·m are observed, which is undesirable. In a system with a fuzzy controller, the oscillation amplitude decreases to 1271 N·m, i.e., by 93.02% or 14.35 times.

Transients on the rotor current are shown in fig. 8–11. The use of a PI speed controller leads to oscillations in the d- and q- components of the rotor current (fig. 8). In this case, the amplitude of the q-component oscillations is 2.54 kA. This leads to the fact that, in the steady-state, the oscillations of the rotor current have an undamped character (fig. 9). No oscillations are observed in a system with a fuzzy controller, however, when the machine accelerates, the d-component of the rotor current increases to a peak value of $1.17 \cdot 10^4$ A (fig. 10). This leads to a large current transient (fig. 11). As a result, the transition time in a system with a PI controller is less by 76.62% (0.54 s).

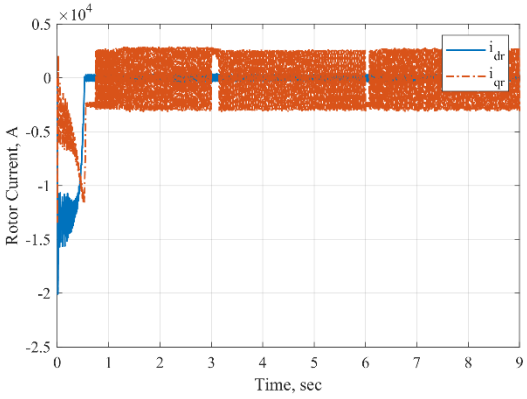

Fig. 8. Rotor current in dq-system using a PI speed controller.

Thus, it is advisable to use the controller of the d-component of the rotor current, which is aimed at increasing speed when using a fuzzy speed controller in the vector control system of the converter of an asynchronous DFIG.

Dynamics indicators for currents in stator windings are close to indicators for rotor currents (fig. 12, fig. 13).

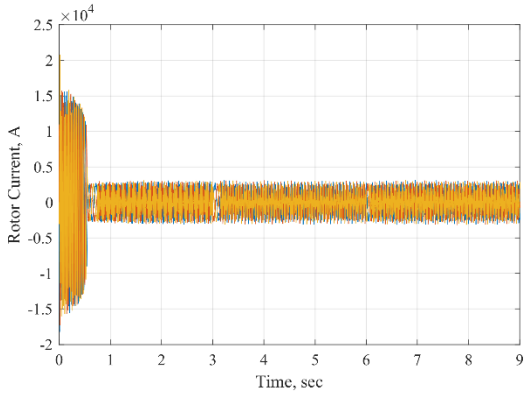

Fig. 9. Rotor currents in ABC-system using a PI controller.

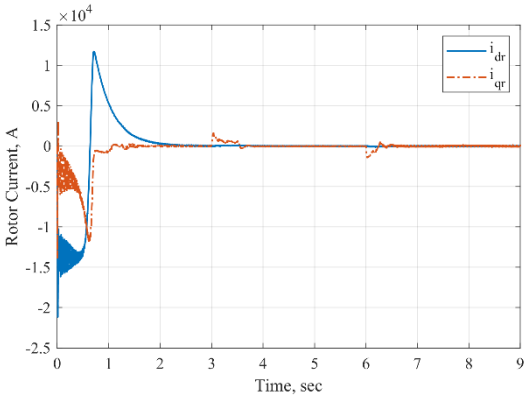

Fig. 10. Rotor currents in dq-system using a fuzzy logic controller.

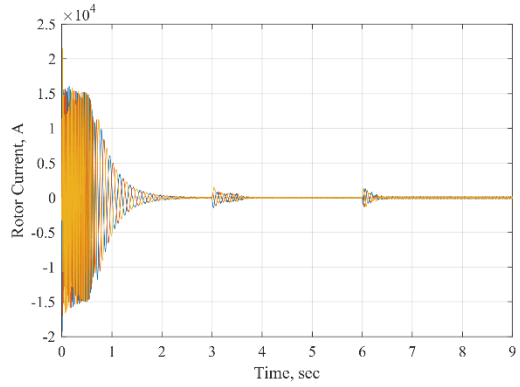

Fig. 11. Rotor currents in ABC-system using a fuzzy logic controller.

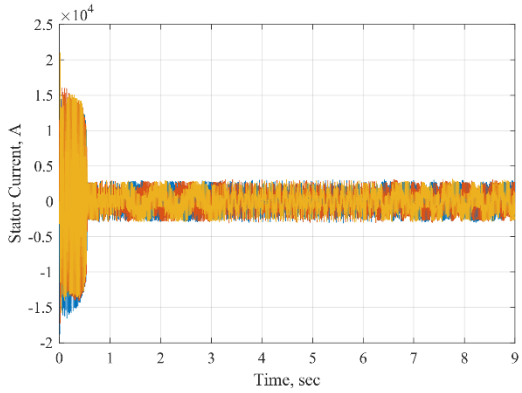

Fig. 12. Stator currents in ABC-system using a PI controller.

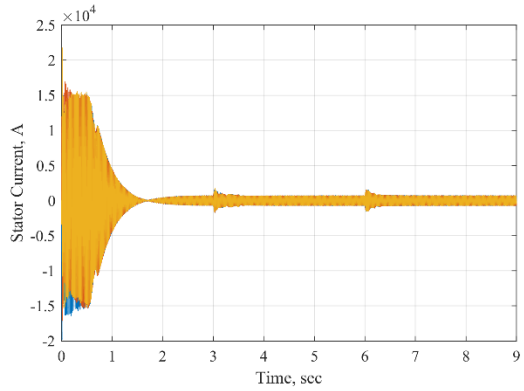

Fig. 13. Stator currents in ABC-system using a fuzzy logic controller.

However, as can be seen from fig. 13, in a system with a fuzzy controller, decreases to 2.14 s the transition time during acceleration of the machine (in a system with a PI controller 0.54 s, which is 74.77% less), but there are oscillations with an amplitude of $0.1 \cdot 10^4$ A in steady states.

Figures 14 and 15 show transients in the d- and q-components of the rotor voltage.

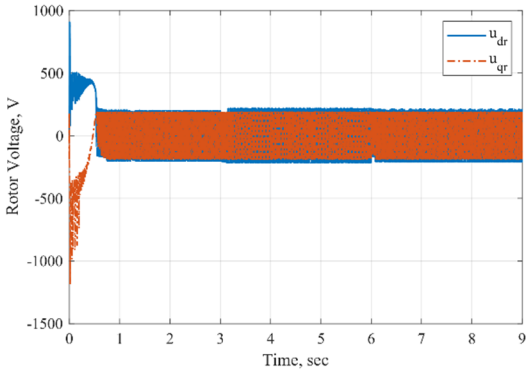

Fig. 14. Rotor voltages in dq-system using the PI controller.

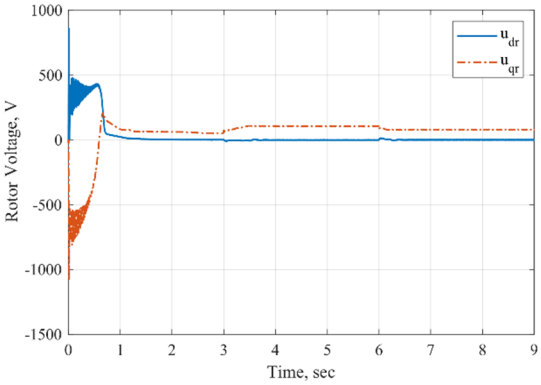

Fig. 15. Rotor voltages in dq-system using a fuzzy logic controller.

When using a PI speed controller, there are oscillations with an amplitude of about 200 V for both components. In a system with a fuzzy controller, transients are aperiodic.

A comparative analysis of the dynamics of vector converter control systems on the rotor side of asynchronous DFIG with a traditional PI speed controller and a developed fuzzy speed controller, which is based on the Sugeno fuzzy inference system of zero-order and Wiener structure, showed that the latter has mainly the best quality indicators transient processes, both in the controlled variable and in the state variables.

Let's note due to which an improvement in the quality of control when using a fuzzy controller synthesized based on self-organization in comparison with traditional PI controllers is achieved. Firstly, the synthesized fuzzy controller implements a nonlinear control law, has a much larger value of the tunable parameters compared to the PI controller and, as a particular case for specific parameter values, it can also implement the linear PI control law, so, in essence, it can be considered as generalization of the law of PI regulation.

Secondly, due to the use of the synthesis algorithm for the base of fuzzy production rules, it is possible to achieve a structure and parameters of a fuzzy controller that is optimal in terms of quality of control and optimized in terms of system control quality.

Thirdly, the choice of the optimal parameters of a fuzzy controller is, in the general case, a multi-extreme optimization problem. The considered self-organization algorithm allows us to consistently increase the controller's knowledge base, thereby synthesizing by sequentially solving optimization problems of low dimension, which partially avoids such difficulties as high computational costs and falling into local minima during optimization.

Conclusions

This article proposes a self-organizing method for the synthesis of fuzzy controllers, based on the zero-order Sugeno fuzzy inference system and having the structure of a block-oriented Wiener system for vector control systems for converters of asynchronous DFIG of wind turbines. When analyzing the indicators of control quality, we considered the implementation of a fuzzy controller of the angular frequency of rotation of the shaft of an electric machine. For a comparative analysis, the classic PI speed controller was used. The results of experimental studies made it possible to establish that the synthesized fuzzy controller provides a shorter transition time in terms of speed, the absence of overshoot, and a smaller standard error in comparison with the PI controller.

The algorithm that synthesizes a fuzzy controller based on the self-organization method is simple and has a low computational load, which allows it to be implemented using digital control devices.

The introduction of vector control systems with fuzzy regulators on wind turbines will allow for high accuracy of regulating the speed of the generator shaft speed while maintaining maximum output power in conditions of changing wind speed. This will increase the efficiency of converting the energy of the wind flow into electrical energy and reduce the cost of generation. The result is a reduction in the payback period of the conversion equipment, and, as a result, an increase in the number of wind farms, which will contribute to the sustainable development of alternative energy.

Subsequent studies will be devoted to the analysis of the dynamic stability of the power grid, which integrates wind turbines using the proposed fuzzy logic controllers.

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Performance of NiO/YSZ anode-supported solid oxide fuel cell fueled with landfill gas stream

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Abstract. Generating electrical energy from landfill gas (LFG) is a challenge due to its low conversion efficiency. In this study, performance of a NiO/yttria-stabilized zirconia (NiO-YSZ) anode-supported cell operating with LFG feed stream was evaluated. This study investigated the potential of solid oxide fuel cells (SOFC) to produce electricity from LFG generated in pilot scale anaerobic municipal solid waste bioreactors. During the initial experiments, power generation was achieved in the SOFC with direct feeding of the LFG. Different feed flow rates (10 - 25 mL/min) and varying temperature conditions (700 - 800 °C) were also investigated to define the optimal conditions. Experiments were carried out at different feed rates and the successful results obtained from 10 mL/min and 20 mL/min feed speeds. It was also observed that the maximal power values were between 0.10 - 0.11 Watt/cm^2 for all experiments. This study showed that SOFCs can provide significantly higher energy efficiencies than steam engines for LFG conversion into electrical energy.

1 Introduction

At conventional waste disposal sites, the aim is both to benefit economically from the landfill and re-open the landfill area at the earliest for beneficial use by eliminating the environmental risks. In a closed landfill, the landfill should be monitored by recirculating the leachate back to the waste mass until all the toxic compounds that are harmful to the environment are completely removed. This is possible if the landfill is operated as a landfill bioreactor. Landfill bioreactors increase the moisture content of the waste, thus the waste is decomposed and stabilized faster. The moisture is usually supplied from the leachate produced in the landfill. By recirculating of leachate, water content, nutrients, enzymes and the bacteria are evenly distributed in the landfill. Landfill gas production will increase, and economic benefit will be gained because landfill bioreactors accelerate the decomposition and the stabilization.

Today, the two most important issues related to energy systems are energy efficiency and environmentally friendly energy production with low emission values. These justifications necessitate the use of a high efficiency technology in electricity generation and transmission. Solid Oxide Fuel Cells (SOFC), which generate electrical energy from hydrocarbons with about 70% efficiency, are among the most important technologies to be used in the future with various design and mechanical improvements. The SOFC systems have higher energy efficiency than the other types of fuel cells (up to 85% with the use of heat released during energy production). These systems are environmentally friendly especially with very low emissions and very quiet operation.

Fuel cells, which are also called electrochemical energy converters, generate electricity and heat through electrochemical reactions by combining gas fuel with an oxidizing gas through an ion-conducting electrolyte. Their efficiency is higher than conventional internal combustion conversions and they produce very little emissions. The difference between the fuel cells of many types depends on the materials used such as electrolyte, anode, cathode and the temperature of use.

The main advantage is the flexibility of the fuel. A variety of biofuels with natural gas, alcohol and hydrocarbons can be used. Fuel cells release electrons, protons, energy and water by using a specific fuel such as hydrogen, methane, methanol, and natural gas. There is no direct combustion in fuel cells. Simply a fuel cell operating principle is based on a simple oxidation-reduction reaction as given in the following equation (Eq. 1).

$$H_2 + O^{-2} \rightarrow H_2O + 2e^- \quad (1)$$

In this reaction, unlike direct combustion, electrons are switched on in a regular and controlled manner, while oxygen ions are passed through a membrane called permeable ions but not permeable to molecules or metal ions. Generally, fuel cells are composed of membranes, such as electrolytes and electrodes. In these electrodes, oxygen and fuel are ionized to produce electrons and water, and oxygen ions are transmitted through the electrolyte while electrons are transmitted through current collectors. The wider the surface of the electrodes, the more they show catalytic activity. Therefore, it is very

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important that the surface area of the electrodes is high. Because the oxygen ions move in the membrane (the electrolyte), the shorter the distance between the electrodes, the lower the resistance across the electrolyte. The high-porosity electrodes and the fuel cell, which consist of a finely stable electrolyte, help to achieve optimum values for high energy. Various reactions take place on the anode and cathode sides of solid oxide fuel cells. These reactions produce different stresses in these regions. The difference between these voltages makes it possible to use solid oxide fuel cells as a battery. The reactions taking place at the anode and cathode are as follows (Eq. 2 through 7).

$$H_2 + O^{-2} \rightarrow H_2O + 2e^- \ (Anode) \quad (2)$$

$$CO + O^{-2} \rightarrow CO_2 + 2e^- \ (Anode) \quad (3)$$

$$CH_4 + 4O^{-2} \rightarrow CO_2 + 2H_2O + 8e^- \ (Anode) \quad (4)$$

$$\tfrac{1}{2}O_2 + 2e^- \rightarrow O^{-2} \ (Cathode) \quad (5)$$

$$CO + H_2O \rightarrow H_2 + CO_2 \ (Anode) \quad (6)$$

$$CH_4 + H_2O \rightarrow 3H_2 + CO \ (Anode) \quad (7)$$

The anode portion of the solid oxide fuel cell is supplied with pure hydrogen, hydrocarbons (gasoline, natural gas – CH_4) or alcohols as fuel. These fuels undergo a processing step to obtain molecules used in the fuel cell for reactions in equations (2), (3) and (4), such as H_2, CO and CH_4. Equations (3) and (4) don't really occur because the equations (6) and (7) are realized much faster. If the equation (3) is realized, carbon monoxide (CO) in the hydrogen gas is also used as fuel, but if the equation (6) is realized, this CO provides H_2 from water and is used as fuel. The same applies to methane (CH_4). The cathode side is supplied with oxygen or another gas such as oxygen-containing air.

There are several advantages of solid oxide fuel cells. For instance, fuel processing and desulphurization are improved due to thermal compatibility. Another advantage of fuel cell is that less cell sintering is required when preparing cell materials and time-dependent deformation is reduced, thus increasing the geometric tolerances. Furthermore, less thermal stresses occur at low temperatures, which will reduce the resistance density of the fuel cell. A wide variety of alternatives are provided for the insulating layers used for sealing in the fuel cell.

Today, fuel cells are one of the most important elements for the widespread use of hydrogen energy and other clean and renewable energy sources. Fuel cells are an electrochemical device that directly converts chemical energy into electrical energy and releases heat only as a by-product. Compared to conventional energy converters, fuel cells have superior features such as high efficiency, reliability, modularity, and noise-free operation. Since it generates both electrical energy and heat, SOFC systems can meet all the electricity needs of a house while meeting the heating and cooling needs. While the efficiency in current energy systems is 30-40%, it can reach 90% in low temperature solid oxide fuel cells. Recently, the SOFC market has been growing significantly [1-8]. Fig. 1 shows a typical solid oxide fuel cell [9].

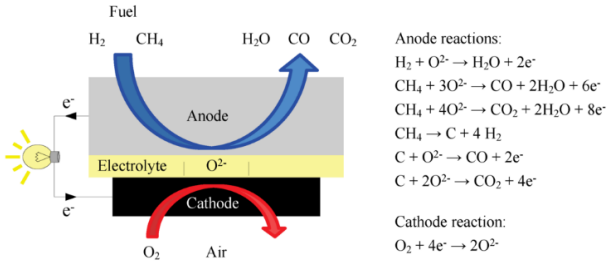

Fig. 1. A typical methane-fed solid oxide fuel cell [9].

As one of the hydrocarbon fuels, CH_4 is the main component of natural gas, which can be used directly in SOFCs. Previous studies have shown that when CH_4 is used as fuel, several chemical and electrochemical reactions occur on the anode side of the fuel cell [10-12]. The result of these reactions consists of six species, which are deposited carbon (C), H_2, CO, CO_2, H_2O and residual CH_4. A probable reaction in the anode is methane decomposition (Eq. (8)):

$$CH_4 \rightarrow C + 2H_2 \quad (8)$$

Removal of carbon using H_2 gas was studied in detail by several authors. It was reported that the separation of surface carbon from Ni/yttria-stabilized zirconia (Ni-YSZ) causes less damage to the Ni-YSZ structure compared to removal of carbon with oxygen [13]. One study investigated the carbon gasification with H_2 in a Ni-YSZ cell and concluded that the gasification rate varied greatly depending on the H_2 concentration [14]. Pure H_2 gas was observed to completely gasify the carbon on the surface of the cell.

Cell stability is an important criterion for SOFC working with hydrocarbon-based fuels. Tao et al. [15] added an additional functional $Ce_{1-x}Ni_xO_{2-y}$ layer to enhance Ni-SDC (nickel samaria-doped ceria) cell stability using hydrocarbon fuels. This cell exhibited resistance to carbon deposition and showed a partially stable open circuit voltage with 0.8% degradation with dry ethanol.

Landfill gas (LFG) is a product of anaerobic degradation and mainly consists of methane (CH_4) and carbon dioxide (CO_2). Thus, LFG is known as a renewable energy source. Waste-to-energy is a well-known concept for landfill sites; however, the high energy content of LFG is typically converted to electricity by using gas engines. This phenomenon has been proved as a low efficient process and has many problems, such as siloxane contamination inside the engine.

The LFG produced in this study is used in the production of electricity with modular and high technology fuel cell systems which are completely environment friendly and produce water vapor only as an end-product. Within the scope of this study, this will be a unique study on converting landfill gas into electrical energy with fuel cells instead of using steam engines. In this study, LFG from a pilot scale anaerobic landfill bioreactor, which contains 900 kg of municipal solid

waste (MSW), was used as energy source for a solid oxide fuel cell.

2 Methodology

2.1 Theoretical background

The energy conversion efficiency of the fuel cells is not limited to Carnot efficiency and can reach up to 90% with the combined heat and power system. One of the expressions of efficiency for fuel cells is theoretical efficiency. Theoretical efficiency is the expression of the maximum efficiency a fuel cell can achieve and is expressed as follows [16] (Eq. 9):

$$e_{ideal} = \frac{\Delta G}{\Delta H} = 1 - T\frac{\Delta S}{\Delta H} \quad (9)$$

where, ΔG, ΔH and ΔS represent Gibbs free energy, enthalpy and entropy, respectively. Assuming that all Gibbs free energy is converted to electricity for fuel cells, the maximum possible theoretical efficiency can be calculated as follows (Eq. 10):

$$e_{ideal} = \frac{\Delta G}{\Delta H} = \frac{237.34 kj.kg^{-1}}{286.02 kj.kg^{-1}} = 83\% \quad (10)$$

Generally, the lower thermal value of hydrogen is used in theoretical fuel cell efficiency calculations. Thus, the yield is more than 83%. The purpose of this here is not to increase the efficiency numerically, but to compare it with internal combustion engines (Eq. 11).

$$e_{ideal} = \frac{\Delta G}{\Delta H_{lowerheat}} = \frac{228.74 kj.kg^{-1}}{241.98 kj.kg^{-1}} = 94.5\% \quad (11)$$

In fuel cells, cell potential decreases during operation due to polarizations. Therefore, the net yield depends on the cell potential V_{cell}. The voltage efficiency can be defined as follows (Eq. 12):

$$e_{voltage} = \frac{V_{cell}}{V_{max}} \quad (12)$$

where, V_{max} is the Nernst potential, or the maximum voltage potential, and V_{cell} is the actual cell potential.

Another efficiency expression in fuel cells is called fuel usage efficiency. Fuel utilization is an expression of how much fuel and oxidant is supplied to the system during conversion. Under actual operating conditions, not all fuel sent to the fuel cell can be converted into energy. In this case, the fuel and some of the oxidant supplied to the system leave the fuel cell before it converts into energy. Accordingly, fuel use is expressed as the ratio of the fuel flow corresponding to the electrical current generated in the system to the actual fuel flow sent to generate the same current.

Three different efficiencies are expressed for fuel cells. These efficiency statements affect the overall operating status of the fuel cell. Therefore, the actual efficiency of the fuel cell is equal to the three efficiency expressions, the theoretical efficiency, the voltage efficiency, and the multiplication of the fuel usage efficiency (Eq. 13).

$$e_{real} = e_{ideal}.e_{voltage}.e_{usage} \quad (13)$$

The stoichiometric ratio, which is the inverse of faradic efficiency, is defined for fuel cells. Stoichiometric ratio is a type of expression that is often used to prevent excess oxidant from being sent during the electrochemical reaction (Eq. 14 and Eq. 15):

$$\lambda_c = \frac{1}{\varepsilon_c} \quad (14)$$

$$\lambda_a = \frac{1}{\varepsilon_a} \quad (15)$$

Anode and cathode stoichiometry for fuel cells is usually more than 1. In other words, more fuel and oxidant are provided above 100% fuel usage value. In the literature, stoichiometric ratio of hydrogen is between 1.2 and 2, while air stoichiometry ranges between 1.5 and 4. In addition, there are many misleading data in the literature regarding fuel efficiency. Fuel usage efficiencies vary according to the flow rate and fuel cell operating voltage [16].

2.2 Design of LFG-SOFC system

LFG was collected from the pilot scale landfill bioreactor (LBR) to a flexible gas sampling bag. Then it was slightly pressurized to sustain a constant flow during the SOFC energy conversion experiment. Inlet flow of LFG was controlled with a gas flowmeter, and different flow rates were investigated to identify the maximal current produced in the SOFC system. Solid oxide fuel cells were first reduced with hydrogen gas to allow nickel oxide-nickel conversion. Then, when the operating temperature reached 775 °C, the input LFG was fed into the fuel cell at different speeds (10 – 20 mL/min). The gas balloon was gently pressurized and fed at constant speed with the help of rotameter. During SOFC experiments, voltage, power and current values were recorded instantaneously on computer assisted system in order to monitor the efficiency of energy obtained from LFG.

Anode supported micro tubular solid oxide fuel cells were used in this study. The cells were developed in a nanotechnology laboratory. Anode electrolyte and cathode materials were NiO-YSZ (50/50, weight/weight) composite powder, 8YSZ (%8 Y_2O_3 doped with ZrO_2) and LSM (lanthanum strontium manganite), respectively. Anode support layers were prepared via thermoplastic extrusion. The active surface of cathode was 3 cm^2.

The composition of LFG produced from pilot scale anaerobic bioreactors was measured by Agilent 6890N gas retention detector gas chromatography (GC-TCD). In GC-TCD analysis, Agilent HP-PLOT/Q model capillary column was used for CO_2 capture and Agilent HP-MOLSIEVE capillary column was used for separation of other gases. Detailed content of LFG used in this study is presented in Table 1. To determine the energy conversion efficiency of the SOFC experiment, voltage, power and current were recorded during the experiment by computer-based control system (Fig. 2).

Table 1. LFG content used in SOFC experiments

Gas	Unit	Value
CH_4	%	51,04
CO_2	%	27,48
N_2	%	12,68
O_2	%	3,53
Others	%	5,27
H_2S	ppm	1105

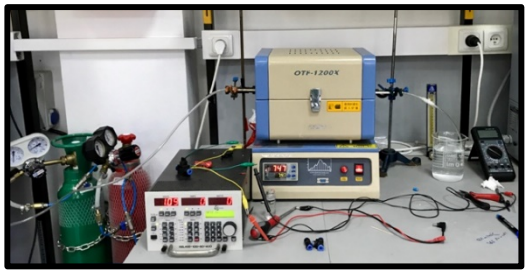

Fig. 2. Experimental set up with fuel cell.

3 Results

LFG is a mixture of gas with high energy value, which mainly contains CO_2 and CH_4 produced by anaerobic biodegradation of organics in landfills. LFG is converted into electrical energy with very low efficiency (30-40%) by conventional internal combustion gas engines. Producing electrical energy from chemical energy with an efficiency of approximately 60% from hydrocarbons, SOFCs will be among the most important energy conversion technologies to be used in the future.

The current-voltage (i-V) and the corresponding power density current density figures when the SOFC is fueled with pure CH_4 and landfill gas are shown in Fig. 3 and Fig. 4, respectively. The open circuit voltage (OCV) values for the Ni-YSZ cells at 775 ºC were measured as 0.42-0.90 V with pure methane as the fuel and 0.21-1.00 V with landfill gas as the fuel with feeding speed of 20 mL/min and 0.14-0.98 V with feeding speed of 10 mL/min (Fig. 3 and Fig. 4). The open circuit voltage values for the Ni-YSZ cells at 750 ºC were measured as 0.09-0.97 V with landfill gas as the fuel with feeding speed of 15 mL/min and 0.08-0.98 V with feeding speed of 20 mL/min (Fig. 5).

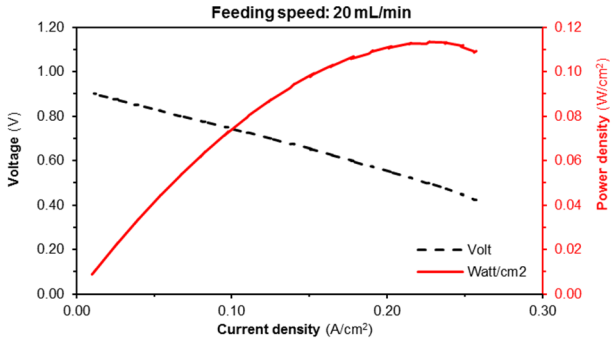

Fig. 3. Electricity production from pure methane gas with fuel cell with feeding speed of 20 mL/min at 650 ºC.

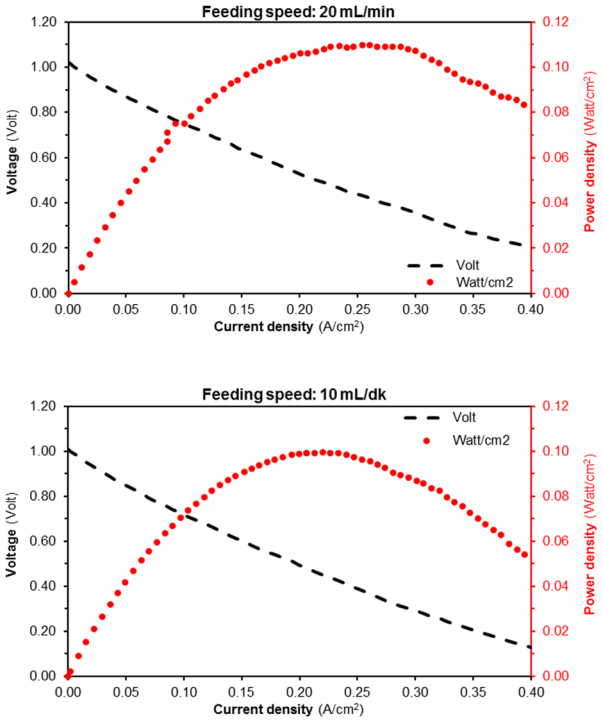

Fig. 4. Electricity generation from LFG with fuel cell with feeding speed of 10 mL/min and 20 mL/min at 775 ºC.

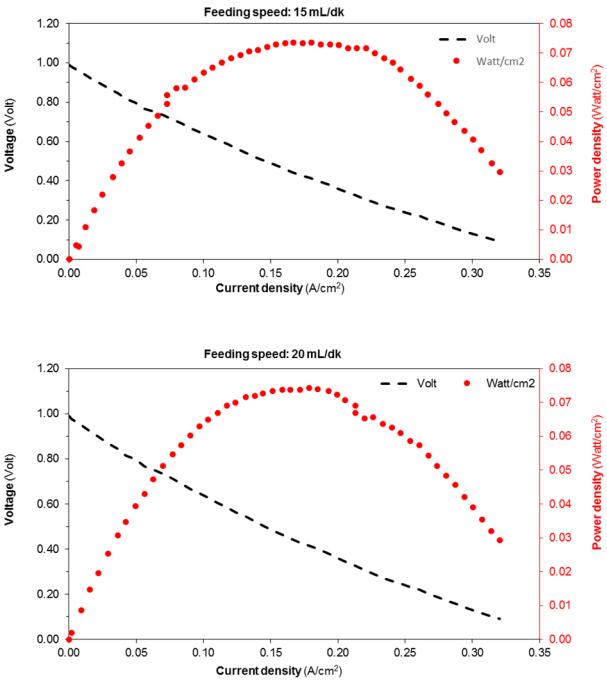

Fig. 5. Electricity generation from LFG with fuel cell with 15 mL/min and 20 mL/min at 750 ºC.

Experiments were carried out at different feed rates and the successful results obtained from 10 mL/min and 20 mL/min feed speeds and the results of the pre-test performed with pure methane gas at 650 °C were compared in Table 2. It was also observed that the maximal power values were between 0.10 - 0.11 Watt/cm^2 for all experiments. It can be seen from Fig 3, Fig 4, and Fig 5 that the highest power densities for the Ni-YSZ cells were achieved at the highest temperature of 775 ºC tested.

Table 2. Electrical voltage, current and power values obtained from SOFC experiments at 775 °C.

Feeding gas	Feeding speed	Voltage	Current density	Power density	Maximum power
	mL/m	Volt	A/cm^2	W/cm^2	W/cm^2
%100 CH_4	20	0,700	0,125	0,088	0,114
LFG (%51 CH_4)	20	0,705	0,121	0,085	0,110
LFG (%51 CH_4)	10	0,709	0,104	0,074	0,099

4 Discussion

Fuel cells are an efficient, combustion-free, virtually pollution-free power source for a green energy production that is perfectly environment-friendly, completely silent and has a few moving parts. The desire for solid oxide fuel cells to be manufactured at larger sizes, with more power, less emissions and lower costs has led to new developments. It was estimated that the fuel cell production has grown by 44% since 2014 – parallel to the increase in solar and wind energy in previous years. This rapid growth is driven by increased demand for energy diversification and the employment of alternative energy sources. Because of increased carbon emissions and extreme climatic events, businesses and communities demand three things: more affordable electricity, more durable power and cleaner energy.

The production of electricity as a result of an electrochemical reaction rather than fuel combustion shows that fuel cells are much cleaner and more sustainable than conventional combustion-dependent technology. Fuel cells are more environmentally friendly in two ways: first, they avoid spreading harmful impurities such as NO_x and SO_2, which are associated with respiratory diseases and poor air quality throughout the world, and the second they reduce greenhouse gas (GHG) emissions. Fuel cells are continually proving to be the most efficient, resilient, and sustainable form of alternative energy generation. As an energy solution that provides both sustainability and power security, fuel cells are the leading power generation technology for businesses and communities now and in the future.

A solid oxide fuel cell fueled with landfill gas has the potential to generate electrical energy, which seems to be an alternative to incineration and landfill applications. However, separating renewable hydrogen from biomass and landfill gas is not an easy task. Furthermore, construction and operation costs are quite high, which can cause customers to avoid risk. Today, those who started using solid oxide fuel cells early started to use government tax incentives and sustainability program grants.

Some of the systems that use direct fuel cells generally operate at 538 °C and use biogas produced by anaerobic digesters. In most projects, the purified landfill gas can be injected into an existing natural gas pipeline that directs it to direct fuel cell units elsewhere. However, it is a fact that landfill gas contains moisture, sulfur and CO_2. For landfill gas-fueled fuel cell systems, desulphurization and moisture removal is required, while stricter pipeline quality is required for bio H_2, thus CO_2 must be removed for directed biogas systems.

5 Conclusions

Nickel-based anodes are suitable for SOFC technology when hydrogen gas is used as fuel. Biogas-SOFC energy system, which uses landfill gas as a feed source, can meet both electrical and thermal energy needs for homes away from the grid. However, the obligation to clean up biogas can have a major impact on the total investment and operating costs and thus complicate the procurement of technology among non-rural communities. Therefore, the choice of a cleaning system technology, in particular for the small-scale biogas-SOFC energy system, should also meet the impurity levels required by SOFC, typically less than 2 ppm for H_2S. For small-scale biogas-SOFC systems, a suitable gas cleaning unit must be very efficient to maintain low pollution levels and also economical for small-scale systems.

In this study direct landfill gas SOFC operation using landfill gas was successfully conducted on anode electrolyte and cathode materials of NiO-YSZ composite powder and LSM at 775 ^{0}C. This study showed that direct electro-oxidation of landfill gas in SOFCs has a great potential. SOFCs can provide intrinsically higher efficiencies than steam engines. It is very clear that SOFCs can offer many advantages for landfill gas conversion to electrical energy.

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PhotosynQ – cloud platform powered by IoT devices

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Abstract. This article describes how to connect to PhotosynQ and some of the features of a cloud service. The focus is on organizing communication between the web service and the Internet of Things. An example and procedure for integrating a number of digital encoders that are not included in the list supported by the default platform through modification of the open-source base firmware is given. It has been suggested that in the future, a number of tools can be designed in the future, including for environmental monitoring, using basic digital sensors included in the so-called Arduino UNO Kit kits and more. It is emphasized that the PhotosynQ web platform, which is related to the SaaS cloud computing model, is an environment for collecting, analyzing, deriving and discussing results where research protocols and calculation procedures are open access. Its primary focus is only on working with a specific list of dashboards, offset by the openness of the software itself, which provides communication with the platform.

1 Introduction

Now there is a growing need for cloud services, computing. Cloud technology is becoming an integral part of many companies and according to IDC forecasts [1], up to 67% of IT infrastructure and software will be implemented with its use.

Over the last 5 years, they have changed not only the IT industry. Ninety percent of US educational institutions have switched to cloud technology [2]. Scientific institutions of the world are no exception.

A variety of web-based software tools used in large-scale science applications help with computation, data integration, analysis, and process automation. Using information obtained through computational procedures, they help scientists to solve applied problems and facilitate the dissemination of data. Here, at least, one should mention the complex research in the field of bioinformatics, the study of brain biology, using network and / or web-based tools for the work process [3].

Cloud technologies and services based on them, in particular PaaS, SaaS, IasS [4], are gradually becoming platforms through which one can explore the environment. Based on these solutions, researchers can build the tools they need to build databases, making all the settings remotely via the Internet.

Of course, today we do not have to talk about a universal cloud service that would satisfy the needs of the scientific community as a whole, and the need to simultaneously use all three of the key aforementioned services that cloud services provide. The diversity of the data set, their heterogeneity, the differences in the amount of data sets, and therefore the need for different computing capacities, the lack of a unified interface for communication and data exchange all require individual cloud service architecture for the specific tasks of users and researchers. However, the main advantages of using cloud platforms are as follows: speed of creation of new applications, flexibility and scalability of the system.

With the development of RFID (Radio Frequency IDentification), WSN (Wireless Sensor Network), NFC (Near Field Communication) and M2M (Machine-to-Machine), which, when integrated with the Internet, allow for easy communication of various technical devices (“things”), another type of platform, namely IoT cloud platforms, is gaining in popularity.

IoT allows you to create a combination of smart devices interconnected by communication networks, and people. Together, they can create a variety of systems, for example, to work in environments that are inaccessible to humans, etc.

With the development of IoT, more objects (“things”) will connect to the global network. In this way, new opportunities will emerge in various spheres of human activity, and new perspectives will be opened to improve the quality of life of the population, in particular by improving the food security of mankind. There is every prospect that in the future, “things” will become active participants in business, information and social processes, where they will be able to interact and communicate with each other, sharing information about the environment, reacting and influencing the processes occurring in the surrounding world.

As platforms grow, so does the need to explore their capabilities and the tools they provide. One of the cloud platforms that is designed to produce exceptionally high-quality field-based scientific results is PhotosynQ [5].

PhotosynQ is first and foremost a network of open Internet data on the status of plant organisms and their phenotyping [5]. Basically, the primary data is obtained through the operation of a tool, a device [6] that captures information from plant objects. The latter is based on the

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chlorophyll fluorescence parameters and characterizes the course of the primary photosynthesis processes. The final data are obtained by processing the primary data and visualizing them with on-line platforms.

This creates a communication platform that connects a large number of researchers, groups of researchers, breeders, farmers, teachers and civilian scientists, creating new opportunities in the direction of research management, raising the level of knowledge about the phenomena and objects under study. Existing PhotosynQ projects are designed to remove barriers between laboratory and field research through the development of tools to study, including the state of plants in dynamic natural environments, etc. [7].

The platform itself is easy to use. According to the developers, it allows not only different users to exchange, compare and analyze the results of the research, but also in its specific setting, to take into account the specifics of the research, to easily adapt the researcher to their own needs.

The stated principles of operation of the said platforms [8] comply with the basic principles of the Internet of Things [9], the key of which is the ability of each object to send and receive data via a personal network or the Internet. This makes the PhotosynQ platform cloud-oriented and capable of communicating with things.

2 Analysis of recent research and publications

Plant phenotyping [8] is first and foremost the main goal of the cloud-oriented PhotosynQ platform. Over the past few years, researchers from more than 25 countries have been using it actively, making hundreds of thousands of measurements. A number of different projects on plant breeding, agronomy and physiology have been obtained and uploaded [8]. Frequent sources [10] inform about the use of PhotosynQ for educational purposes. For instance, Delaware Valley University (USA) student research course, which is part of the University's Experience360 program and is aimed at providing students with practical research experience in the field of biology, is based on the application of this online platform [11]. In total, as of October 2018, the total number of measurements received and processed by PhotosynQ reached one million.

However, one should pay attention to its capabilities in the direction of exchange, data analysis, the ability to customize to meet the needs of both researchers and users in general. In the long run, this can bring it out of the scope of the use only by plant object researchers and provide a tool for collaborative research, such as the natural environment as a whole.

Figure 1 shows the architecture of the PhotosynQ cloud platform [8], which was developed at Michigan State University (Michigan State University, MSU, USA) [5]. The primary and leading role in this scheme is played by devices that can collect all kinds of information, data and disseminate them over communication networks. Therefore, the "thing" in our case is represented by the "device" MultispeQ [8]. This is not in contradiction with Recommendation ITU-TY.2060 [12], concerning the definition of the Internet of Things, since the said device is capable of communication.

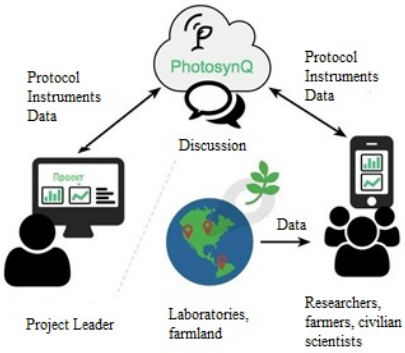

Fig. 1. The principle of organization of the PhotosynQ network [8]

With regard to communication itself, it is known that many network technologies are provided for IoT such as global networks, local area networks, self-organizing wireless networks (ad-hoc) and mesh networks [13]. These communication networks transfer the data collected by the devices to the respective software applications, and transmit commands from the software applications to the devices. Above, we [14] characterized ThingSpeak cloud service as a means of training biology students to monitor and estimate the air pollution of the surface layer of the atmosphere. The prototype that provides monitoring of the human respiratory zone in two districts of the city of Ternopil on the content of suspended particulate matter PM10 and PM2.5 was developed. The main components of the instrument were implemented via microcontroller development system – Teensy 3.2, sensor module (temperature, humidity, pressure) BME280, SenseAir S8 carbon dioxide sensor module, PMS3003 air pollution sensor, Wi-Fi module ESP-01 and online ThingSpeak platform for storing and processing data.

In the case of PhotosynQ, communication between the device and the online platform is accomplished through the mobile PhotosynQ App or its Desktop version [8] using Bluetooth technology, in particular. The power of a mobile device with the appropriate application installed is not only involved in the management and collection of data, but is also used for initial calculations. In the end, the application sends the data to the cloud.

Analyzing the literature, documentation and information support of the site [8], we note that the developers were guided by Open Hardware principles when designing a tool integrated with the PhotosynQ cloud platform [15]. Open access contains documentation on its use and describes the main specifications [7]. The procedure for creating protocols for the study organization is described in detail, the procedure for creating protocols (instructions) for device control is described as well [8]. The latter involve access to a single sensor, both the structural component of the

device and all sensors in general. Given the number of encoders (sensors) that is supported by the firmware of the device, which was created by current owner and project participant Our Sci Greg Austic [16] and Jon Zeeff, we are able to analyze a fairly wide range of physical parameters of the environment or objects, whenever necessary.

According to the developers [8, 17], the device is designed so that if necessary, it can integrate additional necessary extensions, sensors, etc. The core of the "thing" is the Teensy microcontroller [18] that controls all components, sensors. Given that open-source firmware [9] is a principle (specify the type of license), it creates the ability to modify the tool, "thing" for one's own needs.

Therefore, a sufficient condition for communication with the PhotosynQ on-line platform is a Teensy microcontroller with appropriate firmware [17]. Its analysis seems to suggest that, subject to certain, sometimes not very significant changes, support for a much wider range of intelligent sensors (transmitters) can be obtained. Thus, to get a simple tool that will significantly expand the research or teaching tool of a researcher or a teacher accordingly.

3 The results of the research

The hardware to communicate with the PhotosynQ platform.

Our measurement system consists of intelligent, digital sensors (DS), measuring converters (see Fig. 2), which are connected to the signal processing system. The latter is represented by the Teensy 3.2 hardware and computing platform [18]. The hardware, according to its technical characteristics, is able to collect temperature data (−40 to +85 °C, ±0.5 °C), relative humidity (0-100%, ± 3%), atmospheric pressure (300–1100 hPa, ±1.0°hPa), carbon dioxide (CO_2) level (0.04% to 2%), PM concentration (PM 2.5, PM 10, μg/m^3), (measurements range from 0.3 to 1.0; from 1.0 to 2.5; from 2.5 to 10 microns) in the air, the level (ppm) of carbon monoxide (CO) (1–1000 ppm), nitrogen dioxide (NO_2) (0.05–10 ppm), ethanol (C_2H_5OH) (10–500 ppm), hydrogen (H_2) (1–1000 ppm), ammonia (NH_3) (1–500 ppm) methane (CH_4) (> 1000 pmm), propane C_3H_8 (> 1000 ppm) and iso-butane (C_4H_{10}) (> 1000 ppm).

Considering that among our proposed DSs, the components are those supported by the default platform (Fig. 2), i.e. their libraries, the code is integrated into the MultispeQ base firmware [17], accessed according to the instructions [19], in particular through the protocols of the PhotosynQ App mobile application [8].

To expand the list of supported DSs, we have made changes to the MultispeQ firmware. In particular, for the Grove Sensor – Multichannel Gas Sensor MiCS-6814 [22], the Seeed Technology Inc. library is built into the definer.h file [17], for Plantower PMS 3003 sensor – PMS Library-1.1.0 [23]. The code (C++) of both these CAs, which contains its own variables and a list of commands, has been integrated into the firmware as separate functions (Fig. 3), which can be called from anywhere in the sketch, in particular, using the general format of the line instruction (construction) [24]:

```
...
//process single commands
switch (val) {
case hash("get_pms"):
  Serial3.begin(9600);
{
 PMS pms(Serial3);
 PMS::DATA data;
   pms.read(data);
   Serial.println(data.PM_AE_UG_1_0);
   Serial.println(data.PM_AE_UG_2_5);
   Serial.println(data.PM_AE_UG_10_0);
   delay(100);
}
      Serial3.end();
      break; }
```

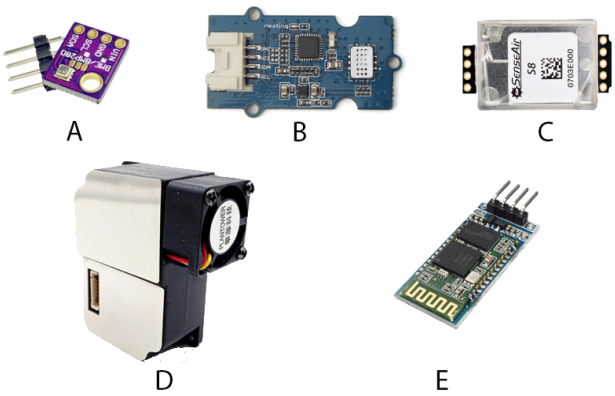

Fig. 2. The main components of the prototype for the assessment of the basic physicochemical parameters of the natural environment (A – BME280 [19], C – SenseAir S8 [20], E – HC-06 [21] are supported by the default PhotosynQ platform; B Grove – Multichannel Gas Sensor [22], D PMS 3003 [23] – require additional firmware.

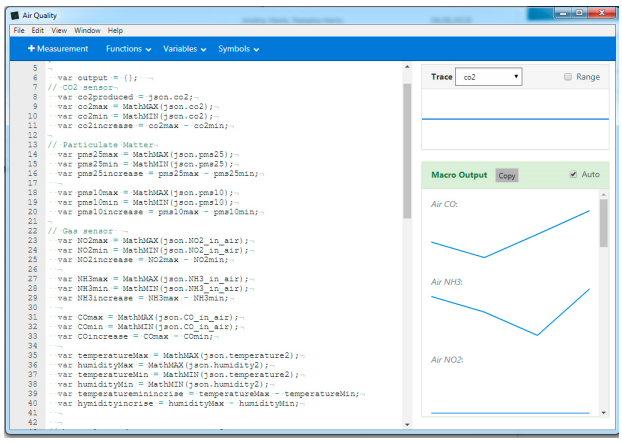

Fig. 3. The PhotosynQ Desktop application window for working with macros [8].

To provide communication with the firmware, we used an open access protocol containing instructions written in JSON [25]. It determines which of the DSs will be involved at a particular moment of time. In fact, access to our integrated sensors is provided through a command in the protocol:

```
[ "pms", 0 ], [ "mgs", 0 ]
```

where, “pms”, “mgs” refer to the corresponding variables contained in the firmware.

Therefore, in order to measure all the above-mentioned physicochemical parameters of the medium and to use the DSs mentioned in the work (see Fig. 2), the following construction should be used in the protocol:

```
"environmental_array": [
  [ "co2", 0 ],
  [ "temperature_humidity_pressure2", 0 ],
  [ "pms", 0 ],
  [ "mgs", 0 ]
]
```

The protocols are related to macros [8]. The latter are written in JavaScript and run after the protocol is complete. By providing computations where the primary data is from the JSON CD values, the macros are responsible for outputting the final calculations on the PhotosynQ Desktop personal computer application or, in the case of a mobile phone, or a tablet, in the PhotosynQ App. Actually a macro for calculating the maximum and minimum concentration of CO_2, the content of particulate matter (particulate matter, (PM)) in the atmosphere, in PhotosynQ Desktop application (Fig. 3) [8] has the following form:

```
var output = {};
// CO2 sensor
var co2produced = json.co2;
var co2max = MathMAX(json.co2);
var co2min = MathMIN(json.co2);
var co2increase = co2max - co2min;

// Particulate Matter
var pms25max = MathMAX(json.pms25);
var pms25min = MathMIN(json.pms25);
var pms25increase = pms25max - pms25min;

//Show value and name in output CO2
output["co2.array"] = json.co2;
output["CO2 increase"] = co2increase;
output["Max CO2"] = co2max;
output["MinCO2"] = co2min;

//Show value and name in output
// Particulate Matter output
output ["PM2.5"] = json.pms25;
output["PM2.5 increase"] = pms25increase;
output["Max PM2.5"] = pms25max;
output["Min PM2.5"] = pms25min;
```

When using only PhotosynQ Desktop software for writing macros and protocols, the platform’s web interface (Fig. 4) is a place where authorized users can create their own projects [8], view, analyze data, search for projects of other users and, if necessary, join them. Actually, the project acts as a kind of data organization [8].

The project we created with the name “Air Quality” is based on the protocol of the same name (protocol ID 1492), which was described above and contains, in addition to the description, a series of questions that must be answered by each project participant before directly performing the measurement.

This approach provides the necessary structuring, categorization of the obtained data and facilitates their further processing, including statistical data.

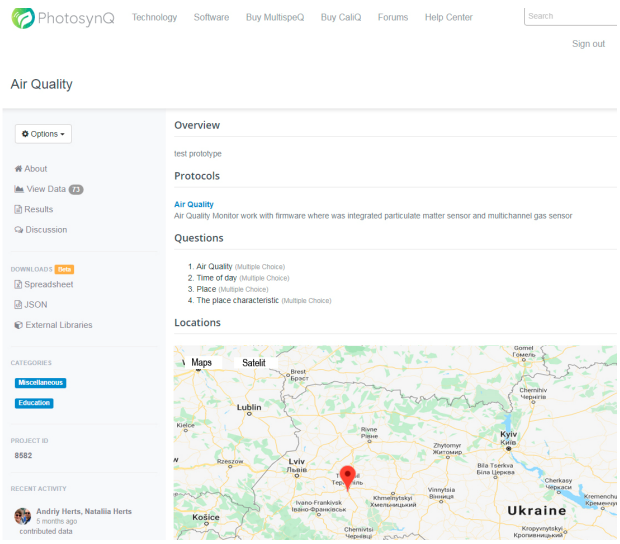

Fig. 4. Web-based Air Quality project interface on the PhotosynQ platform [8].

In order to participate directly in the project (subject to the creation of the above-mentioned prototype), Air Quality, and make measurements, it is necessary to: 1) ensure communication of the prototype with PhotosynQ App or PhotosynQ Desktop; 2) choose from the list of projects needed; 3) answer all the questions listed in the project; 4) take measurements. After the measurement is completed, it is possible to view its results directly on the screen of a mobile phone, tablet (Fig. 5) or the monitor of a personal computer when using the desktop version of the application. After evaluating the quality of the data, it is confirmed or canceled to send the results directly to the website.

The platform has a whole set of tools for statistical analysis (t-test, chi-square test, ANOVA) and data output. If necessary, for additional statistical processing of the obtained data, in our opinion, it is advisable to use the possibilities of R software environment for statistical calculations, analysis and data representation in graphical form. Providing that there are several ways to access the source data and there is a possibility of downloading them in .cvs, .xlsx, json formats, the choice of priority method becomes subjective.

In our opinion, the ability to import datasets directly from a project in Python or R is a very promising solution. In particular, PhotosynQ R (PhotosynQ R package) [7] allows to access our project data by its ID number and generate the required data frame from the R environment.

To generate a data frame file containing the Air Quality project data in RStudio, an integrated development environment (IDE) for R, we executed the recommended [7, 8] set of commands:

```
PhotosynQ::login("login@domain.com")
ID <- 8582
df <- PhotosynQ::getProject(ID)
```

The procedure described in [9] for accessing RStudio software to our aforementioned project with ID number 8582 was successful. For RStudio Cloud, it was similar and did not require the installation of additional libraries.

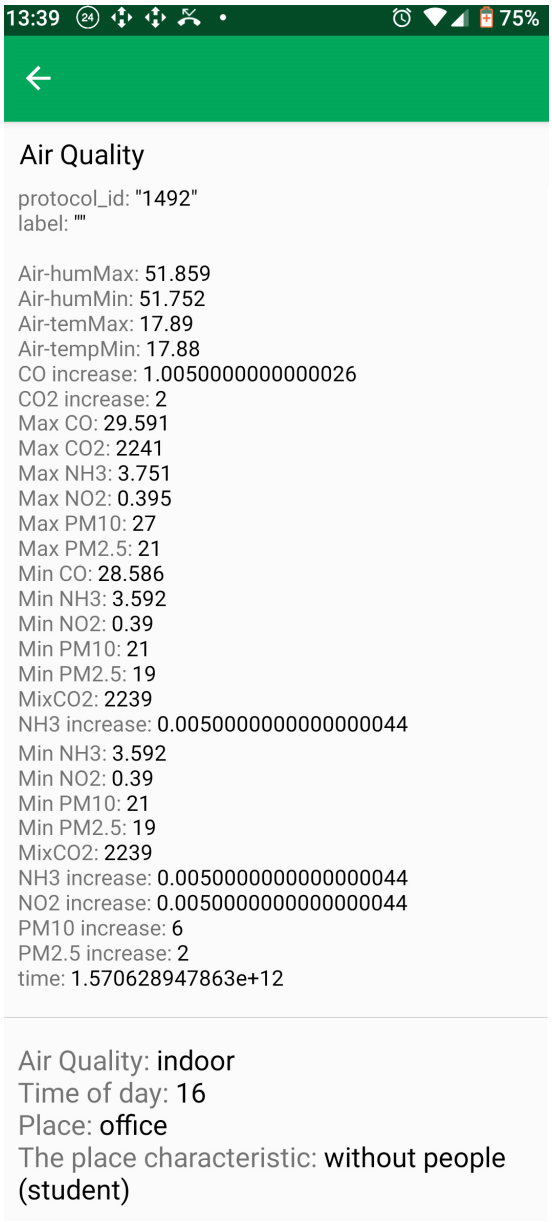

Fig. 5. Presentation of measurement results of the Air Quality project in PhotosynQ App.

Having access, after installation in the Jupyter Notebook environment, which among Data Science professionals is de facto standard for rapid prototyping and analysis of data, PhotosynQ-Python.git from GitHub, to the Web site API [7], each authorized member receives access not only to project data, but also they receive the ability to extend the boundaries of cooperation and beyond.

4 Conclusions and prospects for further research

Currently, hardware connectivity and "communication" with most cloud services is happening through an open API. Ready templates for data connection and processing are offered for this purpose. The PhotosynQ platform provides a data access API, but there is no real-time data visualization and a number of other APIs offered by the services, including ThingSpeak, Ubidot [26, 27]. At the same time, there is an opportunity to display general information about the projects, results and location of the research, etc. This seems logical given that the platform we are researching is primarily aimed at researchers, educators, farmers and citizens who collect, analyze, discuss and exchange information received through portable devices. Considering that the main landmark of PhotosynQ is the collection of data in a well-defined procedure, the user determines the time, place and duration of the process.

The existing firmware contains code that describes the procedure for connecting to it Desktop or mobile application. After receiving information from the device, the commands (procedures) are sent back in JSON format, as they already contain parameters that will determine and define the work of the DSs, the sequence, duration of their work, etc. Therefore, unlike the services mentioned above, which interrogate connected CDs sequentially with a certain user-defined and periodic frequency, the MulispeQ firmware [17], designed to interact with PhotosynQ, is organized so that the user determines the data acquisition procedure, the number of DSs involved at a given time, the sequence and duration of their work, etc. The web platform itself is a place for data collection, analysis and exchange and is not inherently an IaaS or PaaS platform. At the same time, the platform has a whole arsenal of tools for statistical analysis (t-test, chi-square test, ANOVA) and data output.

Therefore, the available firmware used by the PhotosynQ platform to communicate with the fluorometer allows, without further modification, together with the Teensy 3.2 and DSs to obtain, if necessary, a portable measuring device. Support by the BME280, K30 DSs firmware [9] to the color sensor TCS34715 [9] will allow you to evaluate not only temperature, relative humidity, atmospheric pressure, CO2 content, but also the level of illumination in the suites and the spectral distribution in the RGB range. Support for MDX MLX90615 [9] will provide a reading of the surface temperature of the study objects. Available code for the MAG3110FCR1 encoder [9] will allow you to work with a magnetometer and the like.

The suggested approach of inserting additional code into the firmware and successfully plugging in additional sensors, in particular Grove - Multichannel Gas Sensor MiCS-6814, "PMS 3003" enables researchers to tailor the firmware to their own needs, experimenter's needs, or training process, in particular. By inserting the encoder code into the popular kits Arduino UNO Kit or their counterparts from DFRobot, Elecrow, etc., we will get a tool that organizes the communication of a dozen marketed sensors with IoT-oriented PhotosynQ cloud platform, and the similar ones which will greatly enhance the capacity of not only researchers, teachers but also students.

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Geoinformation system for managing non-regular passenger transportation

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Abstract. Today there are a large number of different companies involved in non-regular passenger transport. Most of them use special software to reduce the speed of order processing and for better service management. Such programming tools often provide a convenient system for processing orders and a user interface for the contractors. Therefore, such companies have already forced out other competitors from the market of passenger transport. The purpose of the research is to develop and implement an algorithm of driver's path optimization and to develop a decentralized on-line service, oriented on support of the management of non-regular passenger transport, consisting of a service for car ordering, a service for processing and executing orders and a service for managing internal private organizations. Each service is an application accessible from both a web browser and a mobile device. In the paper the theoretical basis of the management of passenger transport has been analyzed and the basic problems have been defined. The route optimization task, which was reduced to the asymmetrical task of the salesman, was initiated. The Little algorithm for the resolution of this task was used.

1 Introduction

Modern management services of passenger transportation provide a convenient interface and ease of using. But they don't solve all user problems.

There are many different schemes for managing passenger transportation. Some companies have their own vehicle fleet, hired drivers and a database of customers. The other companies provide a centralized service with a database of drivers, customers and orders, and the client applications, used by drivers and passengers for their interactions.

There are a lot of advantages in such services. The driver himself decides the time and the place of his work. He may choose a favorable order for him. Passengers may also choose drivers and share impressions about the trips with them. But also, there are some problems. Trust and security are some of them. Even a rating system and reviews will not always help to solve these problems.

The problem of trust is suggested to resolve with the help of private groups, the drivers and the passengers will be joined in. These groups will be closed and participants will have an access to activate the private mode, thus any other driver or a passenger could not see their order in the system. So, the passenger transportation will only be done by trusted drivers. Drivers and passengers will also be able to combine a private and public mode to achieve the best efficiency of the work.

That is why the development of a service that solves these problems and provides a convenient user interface for passengers, drivers and, most importantly, private groups (organizations) is a very actual problem of modernity.

Also, one of the most important problems in sustainable city development is road traffic. Optimal routing is perspective direction to solve this problem. Minimizing of path's length reduce fuel consumption and tail pipe emissions of carbon dioxide.

2 Problem analysis and the goal of research

Taxi is an important vehicle in urban transport systems. Encouraging taxi passengers can increase transportation efficiency, reduce overall distance, a time, a congestion and emissions. Today many researchers study the taxi problems. Particular attention is paid to the carpooling and its problems and optimization. The analysis of the most famous publications on the problem of taxi and carpooling allowed to determine the main directions of development of carpooling research and their peculiarities.

S. Ardekani represent a method for carpooling when the driver wages, vehicle operating costs and reasonable compensation of other participants depend on the travel time or the distance based on fuel consumption of the vehicle was proposed [1]. It was a first try to find optimal routers for carpooling problem.

In [2] a static optimal control model with a flexible starting price to satisfy market demand was constructed.

Zou proposed to use a transport network model to calculate the shortest path for a car and analyzed the

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influence of road factors on the shortest path [3]. Next researcher developed a model for choosing a taxi route and methods of speed optimization based on the principle of fairness, which provides a minimum time of passenger trip and cost as a target function and guarantees a reasonable income of a driver, taking into account the interests of both drivers and passengers. The genetic algorithm was used to solve this problem [4].

M. Friedrich, M. Hartl, C. Magg represent the static and dynamic modes of working with a car, separating the carpooling mode into several types, such as one to one, one to many, and many to many, and developed the path choosing method and speed optimization model, was investigated [6].

In [5] an efficient model of route planning was proposed and a method for solving the problem associated with the taxi management problem was proposed.

M. Tamannaei & I. Irandoost presents a matching algorithm, which works with typical for agent-based technologies integer and non-integer demand occurring in travel macroscopic model. This approach compares two datasets of suppliers and demanders. Optimal path in the road calculated from sequence of links to a sequence of zones [7].

In [7] minimizes the costs of travel times. Branch-and-Bound (B&B) algorithm find optimal solution of the problem. The large-scale problems were solved by near-optimal algorithm. This model tested on real data from transportation network of Isfahan city, Iran.

In [8] authors present a new heuristic, formulated and tested on real-world, and simulated carpooling problem instances, that mimics a decentralized carpool self-organization process. These findings reveal system-wide savings similar to centralized models, and a potential strategy for improving carpool utilization.

The goal of the research was to develop an on-line service oriented for management of non-regular passenger transportation for different categories of users: drivers, passengers and organizations. Service must also resolve the problem of trust between drivers and passengers and implement an algorithm of driver's path optimization.

The defined purpose determines the following tasks:
- research and optimization of taxi tasks;
- construction a model of route optimization for a multi-route taxi;
- building a carpooling club model;
- optimization the driver's route;
- developing a decentralized model of system functioning and the mode of private passenger transportation;
- designing algorithms for the non-regular transportation management system;
- designing the structure of the non-regular transportation management system.

The main results of the on-line service implementation are car amount optimization and minimization path's length – to prevention traffic jam and protect environment in the big city.

3 Optimization for carpooling routes

3.1 Carpooling club model

There are a large number of people who have travel schedules for work enough stable, but there is also a significant and growing number of travels with multiple destinations and directions that tend to not relate work and non-work travels. People who have stable travels can easily create stable groups of cars for carpooling, and we must also take into account the fact that if a person has to go elsewhere than the destination, this must be included in the group route.

The concept of carpooling clubs is to manage both traditional and dynamic systems in one structure, using their compatibility, and also providing a minimum level of trust between their users through filtering and supporting all groups. The traditional flow of groups is the basis of the system, but when free space is appeared within a group, it can be dynamically distributed to random demand by people who normally belong to another flow in the club (Fig. 1). This system is based on users who can act as passengers, as well as drivers. No one is allowed to act solely as a driver or as a passenger; this helps to increase tolerance and avoid criticism.

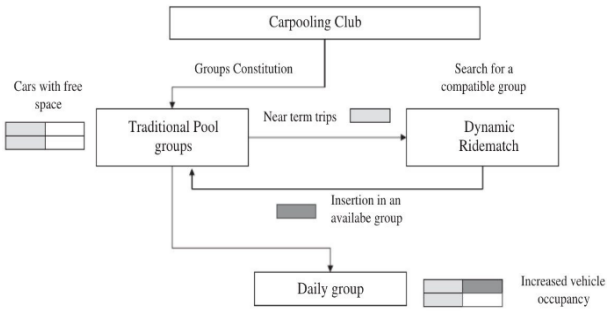


Fig. 1. Carpooling club model.

3.2 Taxi route optimization model

Model conditions:
- Taxi route is independent of the others.
- The capacity of each taxi is 3 passengers.
- Passengers are prohibited from changing the route.
- The taxi speed remains unchanged for carpooling and one-way travel.
- The taxi driver chooses the shortest route.

For a taxi route optimization model, we need to define a target function.

A detour can increase the travel time of passengers in carpooling mode, so a minimum taxi distance can be selected as a target function and optimize the taxi route. The objective function is defined by (1).

$$Z_1 = \sum_{k=1}^{n} \sum_{i=1}^{A} \sum_{j=1}^{A} y_{ij}^{l} q_k^{l} d_{ij} \rightarrow min \qquad (1)$$

where $k \in n$, n is a set of taxis; d_{ij} – distance from i and to j; i and j are adjacent points, $i, j \in A$, A is the number of nodes in the road network; $l \in p$, p is a set of paths for carpooling;

$$y_{ij}^{l} = \begin{cases} 1 \text{ if carpooling}, ij \in l \\ 0 \text{ if carpooling}, ij \notin l \end{cases},$$

$$q_k^l = \begin{cases} 1 \text{ if } l \text{ carpooling path of the vertex } k \\ 0 \text{ in other cases} \end{cases}$$

After defining the target function for the model, it is also necessary to determine the conditions of the delay restriction.

Carpooling can increase the length of travel for some passengers. For the whole system, total travel distances may not exceed distances when using a standard single-route taxi (2).

$$\sum_{k=1}^{n}\sum_{l=1}^{p}\sum_{i=1}^{A}\sum_{j=1}^{A} y_{ij}^{l} q_k^l d_{ij} \le \sum_{k=1}^{N}\sum_{L=1}^{P}\sum_{i=1}^{A}\sum_{j=1}^{A} y_{ij}^{L} q_k^L d_{ij} \quad (2)$$

where $k \in N$, N is a single-way taxi set; $L \in P$, P is a set of single-way taxi routes;

$$y_{ij}^{L} = \begin{cases} 1 \text{ if taxi with single way route}, ij \in L \\ 1 \text{ if taxi with single way route}, ij \notin L \end{cases},$$

$$q_K^L = \begin{cases} 1 \text{ if } L \text{ taxi path with single way of the vertex } k \\ 0 \text{ in other cases} \end{cases}$$

The restriction of the driver income is also needed to be add to the model. Driver income is another condition that follows from this model. It always exceeds the cost of the travel with the longest distance between the passengers in the taxi (3).

$$r_{ij}^{m} \sum_m \sum_i \sum_j y_{ij}^{l} q_k^l q_m^k d_{ij} \ge max\{c_m q_m^k, \forall m\}, \forall k \quad (3)$$

where $m \in S$, S – the set of passengers.

In the modelling process above, it is assumed that all taxis are traveling with a constant speed. However, since urban transport increases, traffic jams occur, so taxi speed cannot be kept constant at all times. In this case, the target function can be defined by (4).

$$Z_2 = \sum_{k=1}^{m}\sum_{i=1}^{A}\sum_{j=1}^{A} y_{ij}^{l} q_k^l c_{ij} \to min \quad (4)$$

where c_{ij} – the distance from i to j.

The problem of taxi carpooling belongs to the combinatorial optimization problems and to the class of NP-complete tasks, so classical algorithms cannot be used.

Since optimization methods are designed to find the optimal solution that satisfies more than one target function, the concept of optimal Pareto solution is introduced in the theory of optimization tasks to find a compromise solution in multicriteria models. The formal definition of the Pareto optimal solution of the problem is defined as follows

$$\min_{x \in X}(f_1(x), \ldots, f_p(x))$$

A valid solution $\tilde{x} \in X$ is called Pareto optimal solution, if there is no other solution such that $f(x) \le f(\tilde{x})$ for all k=1, …, p, and at least for one of them this condition is strictly fulfilled $f_i(x) < f_i(\tilde{x})$, where p is the criteria of evaluation.

Since genetic algorithms proved themselves well as search techniques in large areas with little or no information on the target function properties and constraints, several methods and approaches for using genetic algorithms to solve multicriteria optimization have been developed.

Among representative decision algorithms are the Niched Pareto Genetic Algorithm (NRGA), the Non-dominated Sorting Genetic Algorithm (NSGA-II), and the Strength Pareto Evolutionary Algorithm (SPEA2). All these algorithms have favorable solution efficiency in a particular problem.

The multi-criteria genetic algorithm should obtain the maximum approximation of the set of solutions found to the true Pareto front, at the same time preserving and stimulating the variety of the solutions found, in order to completely obtain the entire Pareto front.

On the flowchart of the algorithm (Fig. 2), Pop represents the population, and Pop is the scale of the population expressed by A. Paretos is the optimal Pareto solution, where Paretos is the number of optimal Pareto solutions in the set of solutions, which is expressed by B. The final conditions have certain restrictions.

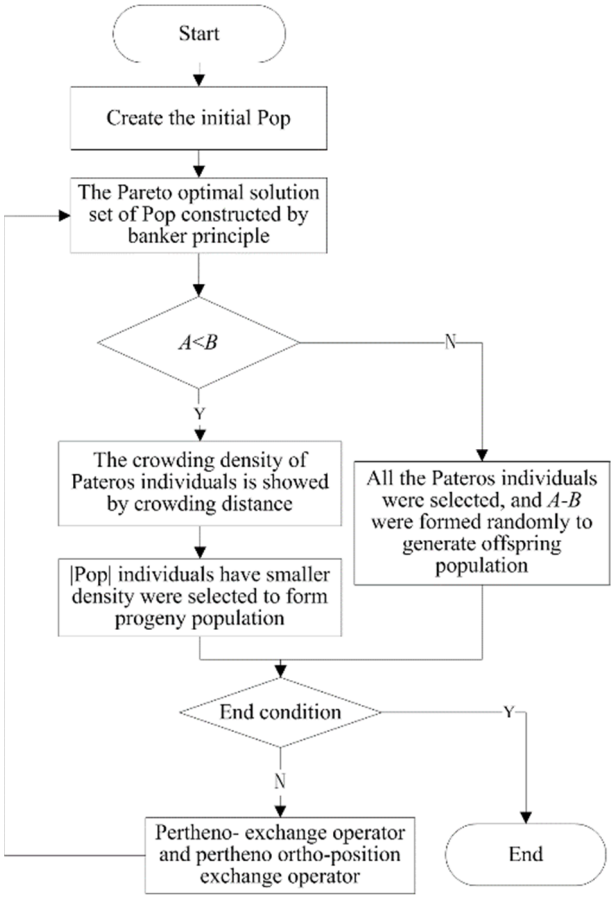


Fig. 2. Block diagram of the algorithm.

4 Design and implementation of separate modules of the system

4.1 Optimizing the driver path

In order to save fuel and a driver time, it is necessary to build the optimal route to be followed by the driver during the passenger transportation. Since an order may contain several destinations, it is possible to describe a model as a graph $G(V, E)$, where the points of destination and a driver location will be the set of vertices (V), and the shortest distances between all vertices will be the set of edges (E). The shortest distances between any two vertices can be obtained by using Google Maps API.

It must also be stated that the shortest distance from vertex A to vertex B will not always be equivalent to shortest distance from vertex B to vertex A (shortest_dist($A \rightarrow B$) ≠ shortest_dist($B \rightarrow A$)), so the graph can have two edges from each vertex to each and should be oriented.

The solution of this problem can be the shortest closed route that passes through all the vertices of the graph exactly one time. In such formulation the problem of the optimal route for the driver is reduced to solving the asymmetric salesman problem. Since the problem is expressed by an oriented graph, it is asymmetric, so there $(n–1)!$ possible routes exist.

Since the problem of finding the optimal route where can be no large dimension is necessary to solve, it is suggested to use one of the exact algorithms, the Little's algorithm.

If we take the driver destination and location as the vertices of the oriented graph $G(V, E)$, and the shortest distances between them as the graph arcs, and impose an additional acyclic condition for the previously set task, the problem of the optimal driver route with no need to return to the starting point can be reduced to a closed variant of the salesman problem (see Fig. 3).

The unclosed variant of the salesman problem is reduced to the closed one by changing the weights of arcs that enter to the start vertex with 0. The optimal closed route of a salesman in such graph corresponds to the optimal closed route of the outgoing graph.

The minimum acyclic Hamilton route, which will begin at the starting point and pass through all destinations, specified by the client exactly once, will be the solution of this problem.

Following such a route, the driver will be able to fulfill the client order for minimal time without returning to the starting point. However, it is often necessary to visit one destination $A(0)$ first (start stop) and another destination $A(n–1)$ last (end stop) among the n certain destinations. In this case, the points between $A(0)$ and $A(n–1)$ should be visited in the most optimal order. Solving a previously set task will not satisfy the conditions of the new task.

As in the previous case, it is possible to formulate a new problem using the oriented graph $G(V, E)$, where the set of all client destinations is the set of vertices V, and the set of shortest distances between each location is the set of arcs E. In this case the location of the driver does not need to be specified in the problem, since his first path will always be the path to the starting point, assigned by the client. After that he will need to follow the route, which will be the solution of the problem. And a minimal acyclic Hamilton route that starts strictly at a point A (client-assigned starting point) and ends at a point Z (client-assigned end point) will be the solution (Fig. 3).

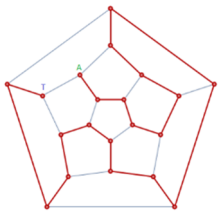


Fig. 3. The minimal acyclic Hamiltonian route, which starts at a given point and ends at the last one.

Since the route must be acyclic and begin and end at the certain vertices A and T correspondingly, the problem can be reduced to the closed salesman problem by adding a new vertex $V(n)$ into the graph. In this case, all arcs leading to vertex $V(n)$, except the arc from the vertex T, must be assigned a weight greater than any possible distance of any Hamiltonian route of the original graph. The arc from the vertex T must be assigned with the weight of 0. This is required to ensure that there is a guaranteed path from the vertex T to the vertex $V(n)$ in the result. Since, if in the cycle obtained during the of solution the vertex $V(n)$ with its edges is rejected, then the vertex T becomes the last in the optimal non-closed Hamiltonian route.

All the arcs coming out of the vertex $V(n)$, except the arc, that enters the vertex A, must have a weight greater than any possible distance of any Hamiltonian route of the original graph. The arc that enters the vertex A must be set its weight to zero. This is required in order to guarantee a path from the vertex $V(n)$ to the vertex A. As a result, if in the cycle obtained during the of solution, the vertex $V(n)$ with its edges is rejected, then the vertex A becomes the first in the optimal non-closed Hamiltonian route.

Based on the research, a problem was set, the solution of which completely satisfies the purpose of the work. This is a problem of minimal acyclic Hamiltonian path that begins at a given point and ends at the last one (see Fig. 3), which can be reduced to a non-closed asymmetric task. Since the solution of this problem is the optimal route, which begins at the first client-assigned point and ends at the point of the last destination in the client order, the given solution completely satisfies our purpose - to find an optimal route for the driver.

4.2 Designing algorithms for the non-regular transportation management system

As the geoformation management system for non-regular passenger transportation is oriented to two types of actors: drivers and passengers, the logic of processing orders, work with other actors and the map was separated on the corresponding modules. Among the main modules

in the system are the module for constructing and displaying the route of the user, the module for creating orders, the module for sending orders and managing them and the module for working with organizations.

All algorithms of the system were implemented in JavaScript language with using the additional libraries. The Google Maps API service was used for geocoding, reverse geocoding and for finding and constructing the shortest path between two specified addresses. The calculations of distance and cost are performed by a separate module based on a path built with the help of Google Maps API.

The algorithm of optimal driver path was obtained by the way of reducing the optimal path problem with fixed start and end points to the salesman problem. The algorithm for solving the salesman problem was implemented using the Little method. Using of Little's algorithm with Google Maps traffic jam detection technologies should reduce fuel consumption more than 30%.

4.3 Designing the structure of the non-regular transportation management system

An event-oriented approach for development was used using RAM cache based on Redis and using Sosket.io for sending notifications.

The non-regular passenger transportation management service (Fig. 4) physically is composed of a Web API service component and a client singe page application that can be deployed with server-less architecture. The client part is not required a server to deploy. Amazon S3 or similar by the functionality platforms for the static content is sufficient to use.

To deploy a smartphone client application, corresponding package is required to install. Structural diagram of the system is shown in Fig. 5.

The business logic of the application is implemented in JavaScript programming language. A monk framework was used for work with MongoDB database. Each collection was built with a wrapper that provides a convenient interface for working with MongoDB.

Redis was used to cache orders, store Sosket.io customer IDs and other operations requiring quick access. To work with Redis on NodeJS, corresponding library node-redis was used, and an additional wrapper was implemented to adapt methods to the system.

To work with Web-sockets Socket.io library was used and a number of classes were written to handle events and send messages. The ConnectionHandler class is responsible for connecting and disconnecting users which open or close an application.

5 The results of the research

After the successful login, the user will see the main page. In driver mode, he will see a map with the locations of other drivers and a block displaying the current active orders from the clients (see Fig. 6).

If the driver mode is switched off, the user will see a page with a map, locations of the active drivers and a block for building the path for his or her order.

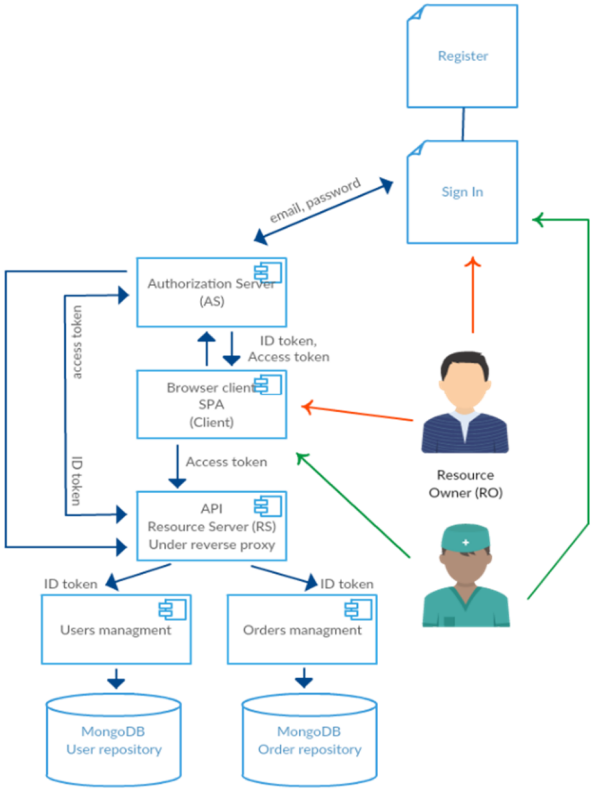


Fig. 4. System services interaction scheme.

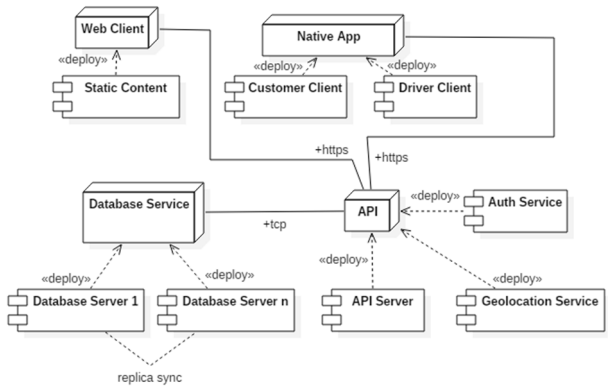


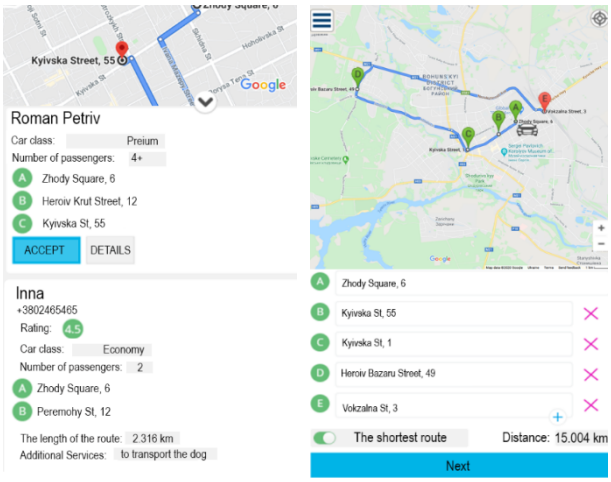
Fig. 5. Structural diagram of the system.

Passengers also have an option to optimize their route and build the shortest possible path. To do this the option "Shortest route" must be selected.

Once the order is created, it is sent to all drivers online, the drivers have 60 seconds to accept the order or decline it. After the first driver accepts the order, it becomes disable for all other drivers, and the passenger will be notified about the accepted order. The passenger must choose: to agree or to refuse to go with the driver who accepted the order. If the passenger agrees to go with the driver – the driver will receive a message about the confirmed order (Fig. 7) and has to go to passenger. Otherwise the driver will receive a rejection message, and all other drivers will again be able to accept the order.

After the order has been completed, the driver confirms its completion and optionally may write a

review of the passenger and evaluate him. The passengers have similar functions. Later the driver and the passenger may again create and accept new orders.



a b

Fig. 6. Main page (a) for the driver and (b) for the passenger with the built path.

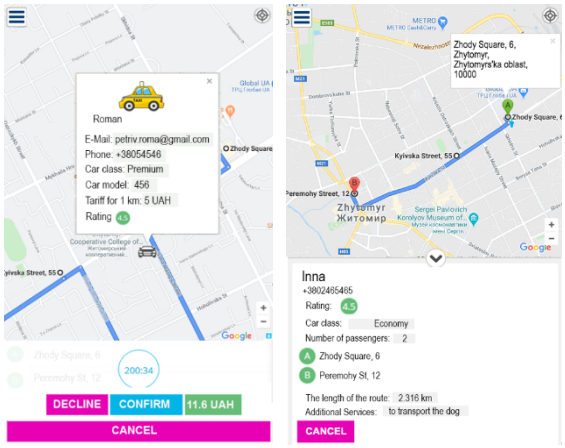


Fig. 7. The order received by the driver and the process of confirmation.

According to the results of the load testing, the service is able to support a large number of users while consuming a small amount of resources. As a result of the security testing, no critical vulnerabilities were identified, and measures were taken to protect against the most common attacks.

6 Conclusions

The passenger transportation management service was designed and implemented in the work.

To solve the set problem, a number of services for performing some useful for the work functions were analyzed.

The main functions of the service are building of paths on the map in real time, the modes of the driver and the passenger, the calculation of the length and the cost of the route, the creation of organizations and private modes of the work.

For implementation of fault-tolerant, highly accessible, reliable and scalable system, a number of technologies were analyzed and those that maximally correspond the specifics of the system functioning were selected. The document-oriented MongoDB was used as the database. To optimize data processing speed, data caching was used using Redis. The client and server code were written in JavaScript programming language. Working with Web-sockets is one of the most important functions of the system. Socket.io library was used for this purpose. The system is based on event-oriented architecture, which provides additional advantage in the resources use.

Algorithms for service functioning were developed and Goggle Maps API was used to implement some of the algorithms for building routes and geocoding.

This system should have positive impact to environment, because optimal transport routers minimize tail pipe emissions of carbon dioxide more than 5%.

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Application of soft sensors in the automated process control of different industries

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Abstract. Sustainable development of industry is closely related with tries to automate industrial processes in all possible ways. Recent advances in automated control systems have led to decreasing the cost of hardware and energy consumption. This article describes examples of soft sensors using in various industries. The main advantages of soft sensors are low cost, flexibility and versatility. In addition, the soft sensors are environmentally friendly as they significantly reduce the amount of equipment and do not require utilization. Despite these benefits, there are some problems with using them. First problem consists in what information and how needs to be measured to use received data in calculation of another virtual data. Second problem is using proper software and the time of mathematical calculations. The goal of the soft sensors is generation of valid virtual data for the controller to increase the accuracy and quality of the automated control. The article is of interest from the point of view of possibilities to applicate modern technology in solving various tasks of automated control.

1 The rationalisation of using soft sensors in the automated control of industrial sites

Increasingly, industrial enterprises are demanding improved production efficiency, following government laws that apply strict restrictions on product specifications and pollutant emissions, leading to increasingly effective measurement and control policies. In the context of the sustainable development of industrial process control, the importance of monitoring a large set of processes variables with the help of adequate measuring instruments is clear. However, the key obstacle to implementing a large-scale monitoring and control policy is the high cost of online meters [1-3].

Mathematical process models based on experimental data, through systematic identification procedures, can greatly help to reduce the need for measuring instruments and to develop a rigid management policy. Mathematical models designed for the aforementioned purposes are known as virtual analysers or soft sensors.

Soft sensors are a valuable tool in many industries, including oil refineries, chemical plants, cement kilns, power plants, pulp and paper industries, food processing, nuclear power plants, urban and industrial pollution monitoring. They are used to solve a number of different problems, such as backup system measurement, “what to do” analysis, real-time forecasting for installation monitoring, sensor testing, and fault diagnosis strategies.

Industries are faced with the choice of an appropriate production policy, which is the result of trade-offs number among various constraints. Final product prices and quality are, of course, two relevant and competing factors that can determine an industry’s market success. Closely related to such aspects are topics such as energy and raw materials consumption, especially due to the ever-increasing prices for energy resources. Moreover, compliance with safety rules (according to several studies, inadequate management of emergencies is the main cause of industrial losses) and environmental pollution problems add to the complexity of the scenario.

Unfortunately, measuring instruments are generally required to operate in adverse or extreme conditions, which on the one hand requires instruments to meet very limited design standards, while a maintenance protocol must be planned on the other. In any case, the occurrence of unexpected faults cannot be completely avoided. However, some measurement tools can introduce significant delays in application, which may reduce control efficiency. Setting up and maintaining a large-scale metering network is never cheap, and the budget you need can significantly affect the total running costs of the plant, which are usually biased to reduce the total number of variables and/or frequency of observations, although in many industrial situations infrequent sampling (lack of online sensors) of some variable processes can present potential performance issues. The typical case is that product quality variables are determined by offline analysis of samples in the laboratory, thus creating a gap and significant delays [4-6].

Soft sensors offer a number of attractive features:

- they are an inexpensive alternative to expensive hardware devices, allowing for more comprehensive monitoring networks;

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- they can work in parallel with hardware sensors, providing useful information for troubleshooting tasks, thereby allowing for more robust processes to be implemented;
- they can be easily implemented on existing hardware (such as microcontrollers) and restored when system settings change;
- they allow you to evaluate data in real time, overcoming the time delays introduced by slow hardware sensors (such as gas chromatographs), thereby improving the effectiveness of control strategies.

There are three basic approaches to building soft sensors: mechanistic modeling (physical modeling), multivariate statistics, and artificial intelligence modeling using neural networks, fuzzy logic, and hybrid methods or algorithms. This classification approach does not have to be very rigid, and techniques specific to one approach are often refined using techniques typical of others.

Appropriate empirical models or data-driven models that generate reliable estimates of real-time process variables based on their correlation with other relevant system variables can be useful tools in industrial applications due to the complexity of installation dynamics, which necessitates the use of soft sensors methods and tools.

Let's consider some examples of soft sensors application by well-known scientists are engaged in the research and implementation of soft sensor technology in automated control systems.

In the article [7] use of soft sensors for the estimation of pollutants in the output flow of a Sour Water Stripping plant in Italy is described. The soft sensors have been implemented by nonlinear data-driven approaches with use of deep learning. The deep learning approach allowed for exploiting all recorded historical data, solving the typical problem of data scarcity. As a result, soft sensors based on neural networks were developed and implemented in the enterprise.

The paper [8] introduces a soft sensor for the estimation of the deflection of a polymeric mechanical actuator. The actuator is based on ionic polymer-metal composites (IPMCs). Applications of IPMCs have been proposed in fields such as robotics, surgery, and aerospace. In such application fields, both the size of the actuating system and the complexity are of chief importance. A soft sensor can be preferred to hardware measuring the actuator output, for estimating the actuator motion. Also, low-order models are of interest to limit the computational load, which can be a constraint in real-time applications. To this aim, several data-driven nonlinear finite-impulse response models have been investigated.

The paper [9] describes an interesting approach for designing a data-driven soft sensor for a plant, in the presence of an unknown measurement delay. For the realisation are used deep belief networks. The features, obtained after the unsupervised learning phase, are exploited for estimating the measurement delay. The procedure is applied to the design of a soft sensor for a debutanizer, which is a part of a refinery settled in Sicily.

The paper [10] analyzes a number of strategies that are devoted to improving the generalization capabilities of neural-network-based soft sensors when only small data sets are available. Authors searched for a strategy that is able to cope with the problem of scarcity of experimental data, which often arises in industrial applications. The methods considered were compared in an industrial case study regarding the design of a backup soft sensor for a thermal cracking unit, working in a refinery plant.

In the paper [11] the soft sensor design strategy for an industrial process, via neural NMA model, is described. In details, the hydrogen sulphide in the tail stream of a Sulfur Recovery Unit of a refinery located in Sicily, Italy, is estimated by a soft sensor. It is based on the minimization of the Lipschitz numbers by a Genetic Algorithms approach. A comparative analysis with an empirical model, developed on the basis of suggestions given by plant experts, is included to show the validity of the proposed procedure.

As can be seen, soft sensors are used in different types of industry and are built using different mathematical mechanisms. The following chapters of article discuss in more detail examples of the soft sensors use by the authors in energy management, the automation of iron ore enrichment processes, and the management of alternative energy sources.

2 Application of soft sensors in the automated control of iron ore enrichment processes

2.1 The complexity of controlling the process of loading the mill with iron ore

Iron ore grinding is a preparatory process for magnetic ore enrichment. Magnetic separation is the main process of magnetizing factories. According to the sustainable development principles in mining and processing it is necessary to build and control systems of magnet-processing factories technological complexes. The pilot or conductive control object is a magnetic separator, and the driven one is a drum mill, the task of which is to open the spores of a useful mineral with an empty rock. The possible degree of ore opening is determined by the nature and size of the grain entrapment. For example, the source iron ore supplied for grinding, classification and magnetic separation is substantially heterogeneous in its chemical composition and texture and structural properties, even within the same deposit. For example, the Ingulets deposit of the Kryvyi Rih iron ore basin is represented by four types of ores: heavily enriched, consisting of carbonate-magnetite and silicate-magnetite quartzites (magnitude of magnetite incorporation 0.008-0.08 mm); medium enriched crushed, consisting of magnetite-silicate and carbonate silicate-magnetite quartzites (magnitude of magnetite incorporation of 0.02-0.2 mm); medium-enriched light-crushed, consisting of red-gray-magnetite silicate and silicate-magnetite quartzites medium and broad-banded (magnitude of 0.02-0.07 mm inclusions); light enriched,

consisting of silicate-magnetite and magneto-silicate quartzites (magnitude of magnetite incorporation of 0.02-0.1 mm). Variables are also the strength of the ore and its density, as well as the mineral composition: magnetite, martite, hematite, iron hydroxide, siderite, sulfides, quartz, silicates, etc.

The main methods of ore preparation at the magnetic concentrating factories are grinding and classification in order to control the particle size distribution of the ore supplied to the magnetic enrichment. Given the uneven composition and variable properties of the ore, there is a need to control the grinding process in order to achieve the optimum size of ore grinding and to obtain the optimal fractional composition of raw materials fed to the magnetic separation.

From the point of view of grinding, the main adjustable variable of the drum mills is the loading or filling the mills with ore, which determines the size of the grinding product at the output of the units. The grinding size significantly depends on the initial enrichment. For example, in the dependences of iron content in concentrate β and the extraction of iron in concentrate ε are presented, depending on the size of grinding (Figure 1).

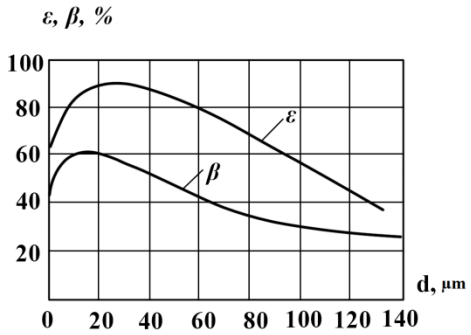

Fig. 1. Dependences of magnetic enrichment indicators according to V. V. Karmazin: ε – extraction; β is the iron content.

The analysis of these dependences shows that there is an optimal size of the mineral opening corresponding to the maximum values of ε and β.

The magnetic separator clearly responds to the fractional composition of the mineral raw material (Figure 2). If the raw material is undergrinded, then the iron yield and content in the concentrate will be less than with well-exposed mineral raw materials. Conversely, if the raw material is overgrinded, the content of iron in the tails will increase, the yield of the concentrate will also decrease.

Thus, a magnetic separator is a natural indicator of grinding results. The optimal size of grinding ore will correspond to the optimum magnetic enrichment.

Therefore, the criterion for optimal loading of the drum mill is the maximum performance of the pilot magnetic separator for the magnetic product.

There is a known relationship between the active power consumed by a magnetic separator motor and the separator performance by a magnetic product. So, the criterion for optimal loading of the ore drum mill is the maximum value of the active power of the magnetic separator drum motor.

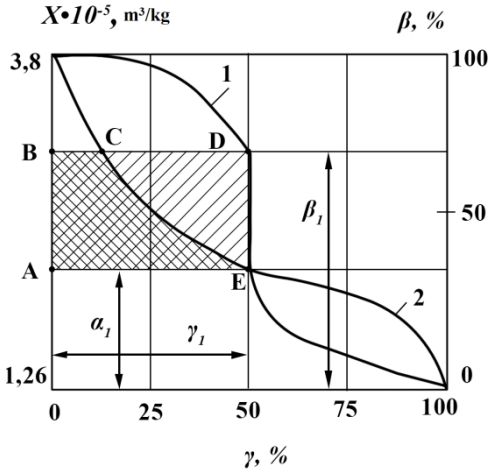

Fig. 2. Enrichment curve for good (1) and bad (2) grinded ore

2.2 Application of soft sensors for automatic control of ore loading process

In order to develop algorithms for the optimization of technological complexes of magnetic ore enrichment with ball mills and milling machines, it is necessary to know the static characteristics of these complexes.

A mathematical model of the technological complex of magnetic enrichment of the first stage (Figure 3) was compiled.

Symbols of Figure 3 have description: φ_p – degree of loading mill with iron ore; P_S – active power of the separator motor; P_M – active power of the mill motor, γ_p - pulp density in the mill.

As a result of the simulation, a static characteristic of the technological complex was obtained (Figure 4).

The analysis of this characteristic shows that to the maximum productivity of the complex in the magnetic product, the active capacities consumed by the mill P_M and the separator P_S are unidirectional, that is, with increasing degree of mill loading with ore they increase. Further increase of loading degree leads to a decrease in the active power consumed by the separators P_S, and accordingly the productivity of the complex by the magnetic product, while the power consumed by the drive engine of the mill increases.

Similarly, the static characteristics of the technological complex of magnetic enrichment with a ball mill of (Figure 5) were obtained.

During the study, it was assumed that the overflow's density of the classifier was stabilized by an automatic density control system at 1400 g/l.

On Figure 4 the following designations are accepted: 1 – large interspersed ore; 2 – medium interspersed ore; 3 – little interspersed ore.

On Figure 5 the following designations are accepted: 1 – 40 t ball load; 2 – 45 t ball load; 3 – 50 ton ball load.

The degree of the ore mill loading φ was measured and stabilized at a predetermined level using a radioisotope fill indicator and a mill loading control system. During each experiment, to collect the

experimental data, the laboratory of the Pivnichnyi GZK (Kryvyi Rih Northern Mining and Processing Plant) selected technological samples of industrial products and tails, performed their chemical analysis of the iron content and determined the volumetric productivity of the separator on the products by measuring capacity and stopwatch, as well as the productivity of the complex by magnitude Q_M. At the same time, readings of measuring instruments of the drive motor active power of the mill P_M and the drive motor active power of the group of magnetic separators of the first stage P_S were recorded. The regression equation was obtained

$$P_S = 16.7 + 3.27Q_M \quad (1)$$

which confirms the possibility of measuring the performance of the technological complex by magnetic iron Q_M by the amount of active power consumed by a group of magnetic separators. According to the results of the experiment, the energy consumption per ton of the obtained magnetic product was simulated. The correlation coefficient between the variables Q_M and P_S was 0.89.

Since the active power consumed by magnetic separators, P_S is proportional to the performance of the complex over magnetic iron Q_M, then the maxima of static characteristics $Q_M = f(\varphi)$ and $P_S = f(\varphi)$ must coincide. Therefore, an increase in the degree of loading of the ore mill φ leads to an increase in the active power P_S consumed by the magnetic separators and the active power P_M consumed by the mill. Further increase in the degree of mill loading with ore leads to a decrease in the performance of the complex on the magnetic product Q_M and, accordingly, consumed active power P_S by the separators, while the power P_M consumed by the drive engine of the mill, increases.

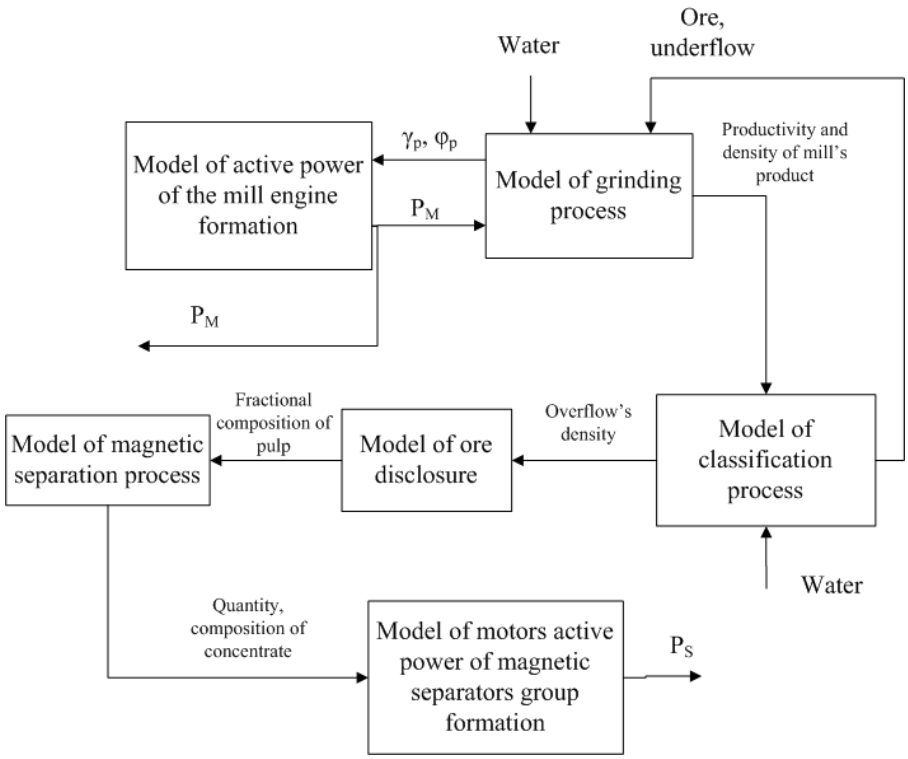

Fig. 3. Scheme of the model of information transfer between mechanisms on the course of the technological complex of magnetic enrichment.

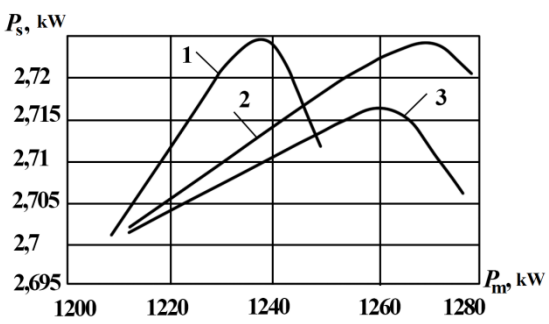

Fig. 4. Static characteristics of a technological complex of magnetic enrichment with a mill of wet selfgrinding.

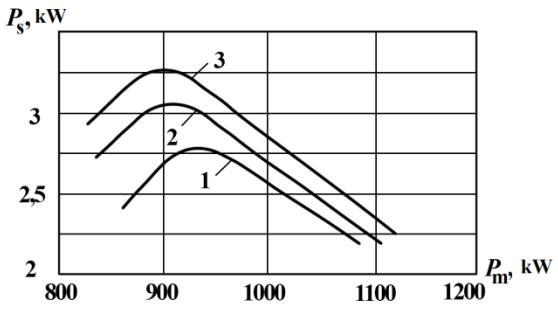

Fig. 5. Static characteristics of the technological complex of magnetic enrichment with a ball mill.

The conducted researches confirm that it is advisable to use soft sensors to control the process of loading the mill with iron ore, namely to control the degree of the mill loading with ore, given the active power of the magnetic separator motor.

3 Using of soft sensors in the automated control of solar power plants

In any real system, such as a solar power plant, a data collection system must be put in place to monitor performance, which provides monitoring of the parameters that are important to the system. There are many methods that use classic hardware to collect and transmit data, but in large solar power plant, this can be quite expensive due to the large amount of sensors required and therefore impractical to implement. In solar plants, such controlled parameters are the output power, voltage and current at the panel output, its temperature, and in the case of solar tracking systems – the angle of inclination to the horizon and the angle of rotation of the panel. Such a system has a complex relationship between all parameters, and therefore the technique of obtaining one or more variables from another measured value can be applied. That is why the use of virtual sensors, or so called soft sensors, is most appropriate in terms of reducing the amount of equipment needed and, as a consequence, its cost.

However, this is not the only one property of soft sensors. If there is already a sufficient set of equipment and sensors in the solar power plant, the use of virtual sensors can improve control accuracy. Sometimes, the sampling rate of real sensors is not high enough, which does not match the capabilities of the controllers. Therefore, by increasing the amount of data received by the controller, it can be improved: the controller receives a signal from real sensors every T seconds, and additionally, from virtual sensors every $T/5$ seconds. This method, in which the data processing speed of the controller is N times greater than the actual sensor sampling period, is called multi-rate. And at times when real-world sensors can't get information due to certain unforeseen circumstances, soft-sensor information allows the controller to continue its control task at the normal level, the effects of missing information are minimized.

The block diagram of the system using the soft sensor based on a mathematical model of a multi-rate process is shown in Figure 6. In this system, the soft sensor works in parallel with the real sensor, and in real-time receives data from it and additionally receives a control signal coming from the controller to the actuator. The advantage is that the effects of delay in the transmission of the control signal and the sampling rate of the real sensor on the real process are taken into account in the virtual environment, providing more reliable virtual data from the soft sensor.

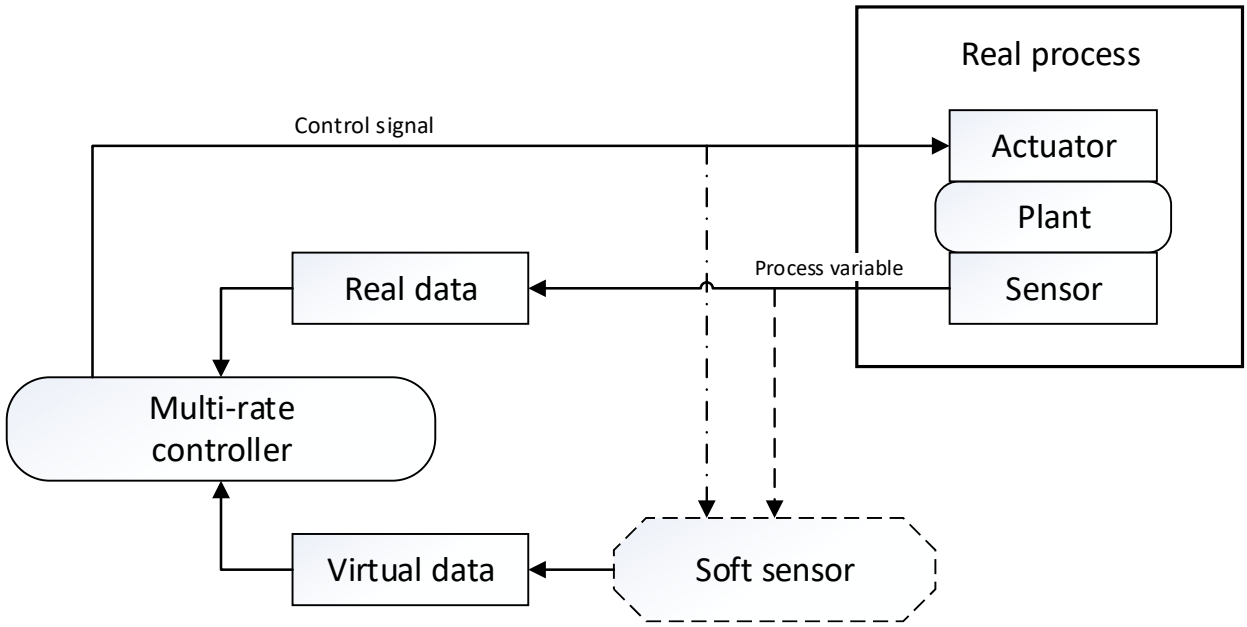

Fig. 6. Block diagram of a soft sensor control system.

According to Figure 6, the multi-rate controller uses virtual data obtained from a soft sensor based on the process model to calculate additional control actions sent to the actuator. Thus, the triggering process is faster than the actual sampling rate of real sensors, overcoming the problem of limiting the sampling rate of those sensors.

As noted above, we are considering the implementation of soft sensors for a solar power plant. One of the most important parameters of this system is the maximum power of the generated electricity. Maximum power point tracking is a must to maximize the efficiency of converting solar energy to electricity using solar panels. Directly the power is affected by the amount of solar irradiance per 1 m^2 of solar field: the more solar energy, the greater the output power of the system; and partial shading dramatically reduces the amount of electricity. Therefore, it is important to receive timely data on the level of solar irradiation to

adjust the position of solar panels. Complex instruments such as pyranometers or pyrheliometers are used to determine the amount of solar radiation per unit area. But their cost is too high to install many sensors across the entire solar power plant. The maximum power of the solar panel directly depends on the performance ratio *PR*:

$$\boldsymbol{PR} = \frac{\boldsymbol{P_i}}{\boldsymbol{P_{nom}}} \frac{\boldsymbol{G_{STC}}}{\boldsymbol{G_i}} \qquad (2)$$

where, P_i – measured instantaneous power, P_{nom} – nominal power of the panel, G_i – actual instantaneous level of solar radiation, G_{stc} – solar radiation under normal conditions. Almost all of the values in the (2) are known: the nominal power is given in the solar panel technical data sheet, the instantaneous power can be measured by multiplying the voltage U_i and the current I_i at the output of the panel, and solar radiation under normal conditions can be obtained from the statistics from the geographical location of the solar power plant. The amount of solar radiation that falls into the panel at the moment can be calculated from formula (2):

$$\boldsymbol{G_i} = \frac{\boldsymbol{P_i}}{\boldsymbol{P_{nom}}} \frac{\boldsymbol{G_{STC}}}{\boldsymbol{PR}} \qquad (3)$$

where, *PR* is applied as coefficient of 0.6–0.8 as for normal panels functioning.

In this way, the soft sensor will calculate the instantaneous solar radiation for the panel positioning system relative to the sun to possibly increase the electricity generated and improve the efficiency of the solar power plant. And in the case of dividing a large field of several hundred or thousands of solar panels into separate sections, calculate the solar radiation for each of them to position these areas independently of each other, to minimize the effects of partial shading of the panels by clouds.

4 Soft sensors using approach in industrial reactive energy measuring

Sustainable development of industry is associated with increasing requirements for the quality of the supplied electric energy. Moreover, a very important factor is the ability to accurately measure the power flowing in the network at any level. This is important for both suppliers and consumers of energy. With increasing productivity and improving the quality of finished products of industrial enterprises, their consumption of energy resources also grows. At the same time, the requirements for the capacity of the power lines of these objects are increasing. The observed trend of a significant increase in the share of non-linear and non-stationary loads in power networks leads to a reduction in the throughput of these distribution networks due to an increase in the reactive capacities flowing in them. This problem is associated with the increasing use of power electronics devices among other consumers of electric energy. Examples of such devices include induction furnaces and heaters, gas discharge lamps, variable speed drives, etc. The growth of reactive power flowing in the enterprise network creates a large amount of interference for the enterprise itself and adversely affects the entire distribution network. Also, the fact that such consumers are becoming generally accepted leads to the fact that the equipment on the consumer side and on the side of the electric energy suppliers operates in non-sinusoidal signal modes, which adversely affects the accuracy of measuring instruments. And in conjunction with the growth of reactive power flowing in the network, it leads to an increase in losses during the transportation of electric energy and a decrease in the power factor of consumers. The measurement and control of the adequacy of the reactive power measurement system is associated with a set of problems, including the high cost of such a system for large industrial facilities, such as mining and processing plants, because of their distributed structure and the supply of different structural units of such an object to different power lines from different distribution substations. In such a situation, as a possible solution to this problem, we can consider the analytical calculation of reactive power volumes through other simply measured parameters of the distribution network. So when considering the distribution system of electric energy and the nature of the loads connected to it as linear and operating exclusively in the mode of sinusoidal signals, the reactive power is determined by a simple ratio:

$$Q = U \times I \times sin\varphi \qquad (4)$$

Where: I is the effective value of the current strength in the network; U is the effective voltage value in the network; φ is the phase difference between current and voltage.

When considering the operation mode of the system under the influence of non-harmonic signals, the effective values of voltage and current in the network can be expressed as:

$$I = \sum_{k=1}^{K} I_k \sin(2\pi k f_0 t - \psi_k) \qquad (5)$$

$$U = \sum_{k=1}^{K} U_k \sin(2\pi k f_0 t - \theta_k) \qquad (6)$$

Where: k is the harmonic number of the sinusoidal signal of frequency f_0; I_k is the effective current value of the k harmonic; U_k is the effective voltage value of the k harmonic; ψ_k and θ_k are the initial phases of the signals; K is the total number of harmonics considered.

As can be seen from the above expressions, the analytical solution to the problem posed is associated with an even greater number of difficulties due to the large number of additional difficult to measure quantities. Based on this, it seems logical to use soft sensors for calculating reactive power. Let us consider as an object the mining and processing plant mentioned above. We make the assumption that, within the framework of one distribution substation, the consumption of reactive power by each structural element of the object affects the consumption of the others. In this case, the structural element with the largest volumes of reactive energy consumption should have the greatest influence. To verify this assumption,

we use statistics on the consumption of reactive energy of the mining and processing plant. There are statistical data on the consumption of reactive energy by the four structural elements of the facility, which are supplied with electrical energy from one distribution substation. A fragment of statistical data on the consumption of reactive power by four structural elements of an object with a measurement frequency of two hours during one day is given in the Table 1.

For a complete set of available statistical data, we will calculate the correlation coefficient of the reactive power consumption of the structural element with the highest consumption of other structural elements. The calculation was carried out according to statistical data for 7 calendar days. The result obtained in the form of correlation coefficients of reactive power consumption by objects 2-4 with object 1 for a period of 7 days is displayed in the Table 2.

Table 1. Statistical data of mining and processing plant reactive power consumption.

Time, h	Obj. 1, kvar*h	Obj. 2, kvar*h	Obj. 3, kvar*h	Obj. 4, kvar*h
02:00	14348	46	102	972
04:00	13218	45	53	912
06:00	14649	47	102	912
08:00	14471	49	106	792
10:00	13771	50	101	80
12:00	11534	48	96	804
14:00	12790	43	127	1020
16:00	13077	48	98	1224
18:00	12552	43	98	804
20:00	12344	5	119	996
22:00	13760	5	94	888
24:00	12400	6	95	732

Table 2. Correlations coefficients of structural elements reactive power consumption

Day	Element 2	Element 3	Element 4
1	0,569	0,303	0,659
2	0,741	0,469	0,897
3	0,433	0,498	0,965
4	0,565	0,443	0,759
5	0,728	0,248	0,903
6	0,715	0,645	0,796
7	0,638	0,459	0,956

From the obtained correlation coefficients, we can conclude that the initial statement about the relationship between reactive power consumption by the structural elements of the mining and processing plant within the boundaries of one distribution substation is correct, and the obtained data can be used to further search for mathematical patterns and develop a soft sensor to predict the reactive power consumption value of all structural objects of the mining and processing plant that are supplied with electrical energy from one distribution substation based on the value of reactive power consumption of one of these elements.

5 Analyse of obtained results

The analysis of soft sensors using in the automated control of various industrial processes shows their versatility and benefits. The use of soft sensors is often a more viable alternative to hardware, as very often physical sensors have to operate in extreme conditions, are quite expensive and need frequent replacement. It is advisable to use soft sensors in the case of a large number of similar mechanisms operating in approximately the same conditions. Measuring certain performance of one mechanism, you can roughly judge the situation as a whole.

Unlike sensors made from various material substances, soft sensors have a different basis. By definition, “soft sensors” are based on the use of software and the calculation of regulated process parameters. Thus, the environmental friendliness of their use is not in doubt.

At the same time, it is not necessary to check such sensors for the content of harmful substances and hazardous emissions during their operation. At the end of their life cycle, one does not have to worry about compulsory utilization.

As for the status of a sustainable product, the application of software solutions has a long-term perspective on sustainable development.

Soft sensors can be built on different technologies. These can be physical implementations that combine several heterogeneous primary and secondary converters in their design. But more often, soft sensors are modelled virtually on the basis of mathematical devices of fuzzy logic, neural networks, adaptive systems, etc. The choice of mathematical apparatus depends entirely on the specific situation and the specific task.

The main difficulty in working with the principles of soft sensors is lack of knowledge about them due to their novelty and, as a consequence, the lack of conventional mathematical descriptions or structure. On the other hand, it opens up opportunities for creativity.

In general, to work with soft sensors it is necessary to have large arrays of statistics for calculations. It is necessary to have a good understanding of the controlled process principles, physical features and find correlation between the parameters.

The review results suggest that the soft sensor instruments can significantly reduce the amount of mechanical equipment and, through calculated correlation dependencies, delegate the task of measuring certain process parameters to software.

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Autonomous navigation system with small four-wheel drive platform

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Abstract. The task of achieving greater flexibility and maneuverability of small transport and service units' motion in modern factories by developing small autonomous navigation systems plays crucial role in complex automation of transport logistics nowadays. To solve navigation task, it was proposed the following approach, where as a means of assessing the environment was used computer vision system based on 5-megapixel CMOS image sensor and for the front obstacle detection was used auxiliary ultrasonic sensor as a limit switch. Authors solved the problem of yawing using artificial marking approach as along two-colored leading lines. For maneuverability increase during the turn was used speed movement control based on lines perspective. The basic design and technical characteristics of the four-wheel drive platform and the algorithm of the Raspberry PI 3/Arduino Nano hybrid control system are presented. Experimental results proved the viability of the proposed approach.

1 Introduction

According to last report of Grand View Research company [1], the global Automated Guided Vehicle (AGV) market is dynamically growing. This is thanks to the rising demand of automation systems based on computer vision technology. This type of systems has found wide application in transport logistics, assembly, packaging and storage facilities. The automotive, food, aerospace, pharmaceuticals and retail sectors most of all need this technology to make the service operation process safer for personal and other co-operating technological equipment. AGV gives ability to increase productivity and minimize operational costs by using Industrial 4.0 technologies workspace organization [2]. The automation equipment offers a number of classic and innovative solutions to reach high flexibility with approved cost-effective techniques in implementation. In addition to large systems such as robot platforms, small transport and service units are capable to perform path observation, complete simple operations as monitoring and, in some cases, can be combined into a cluster to increase the availability by spatial configuration with one or several control units.

Rapid development of computer systems and workspace recognition techniques, together with the increase of units' number working together and the decrease of their cost, stimulate research of new and combined solutions based on the available hardware and software systems. Smart sensors give opportunity to analyze working space by several spots with common dataset. The use of modern automation systems and technologies in navigation allows us to introduce new approaches in solving these tasks.

2 Formulation of problem

Improving the efficiency and functionality of small transport units for production and service includes a wide range of tasks such as transport logistics optimization, autonomous navigation and path planning, stability of the motion characteristics in a loaded / unloaded state, safety of transport and service operations, distribution of computational power among control units etc. The workspace is generally characterized by growing the intensity of traffic flows with a large number of situations which require rapid response. Finding a solution is usually a compromise between the complexity and reliability of the system and the ability to real-time reconfigure the base route in the workspace.

3 Literature review

Under the conditions of small-volume flexible production, small autonomous transport systems are in the wide demand. They give the possibility of monitoring or transporting small parts in trays or carriages in limited workspace. The popular techniques for navigation use magnetic and colored tapes, light reflective tapes with laser scanning, radio spots, computer vision system and systems with inertial adjustment of motion. Some important works in this field devoted to use special techniques of autonomous navigation.

The paper [3] describes the use of magnetic and color bands, light reflecting bands with laser scanning, radio

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beams, systems of vision and inertial motion control for the construction of navigation systems. However, the problem of recognizing objects that may intersect a route (according to the trajectory of the object) is not resolved.

In the paper [4], the authors propose a combination of an ultrasonic sensor with a computer vision system to accurately determine distances to the frontal obstacle. However, the proposed system is used for free route planning and is very complex in data preparation for recognition in advance.

In papers [5, 6], the authors propose free-motion systems based on lidar, capable of recognizing the surrounding environment for maneuvering. However, the sensors proposed in the papers provide limited detail for interacting with objects using color techniques.

The works [7, 8] are devoted to autonomous navigation along a fixed route, constructed using proportional-integral-differential (PID) and neuro-fuzzy control laws, mainly based on deterministic and / or simulated data sensors. However, the works do not pay attention to the fact that in the case of computer vision, a sufficiently complex filtering and algorithmic adaptation to the workspace is required.

Articles [9, 10, 11] describe modern sensors for measuring acceleration and distance to objects. However, they do not indicate the feasibility of using them in the design of autonomous mobile platforms. The possibility of replacing them with artificial marking systems has not been indicated.

Using the computer vision system gives good opportunity to estimate a lot of workspace parameters for navigation. However, the sensor work is affected by a variety of environmental conditions, on which the result of recognition depends. One of the main recognition problems is the uniformity of illumination and the presence of glare surfaces. Even in the conditions of artificial lighting, brightness level changes as a result of the appearance and disappearance of objects with different light reflecting and light absorbing properties. Additional artificial marking of routes like colored leading lines and markers can also simplify or improve the navigation task, but the problem of objects recognition which cross or can cross the route (according to trajectory of object movement) is still present. So, the ability to recognize objects and obstacles in workspace variably to each situation is an intellectual task.

The use of powerful embedded computers and flexible software tools gives an opportunity to solve complex data processing tasks on small autonomous mobile platforms.

4 Proposed work

The aim of this study is to implement an autonomous navigation system based on computer vision and ultrasonic sensor that are placed on a small four-wheel drive (4WD) platform as a prototype of AGV. The tasks considered in this paper include electric circuit design and control implementation taking into account raw data filtering along the path. Solving them will let proposed small 4WD platform autonomously navigate along a defined route with the future ability to detect the obstacles. In our study we define the following assumptions: 1. the workspace is a closed facility area; 2. navigation task includes preliminary determined location, geometric parameters of technological equipment and the artificial lighting scheme of the workspace.

4.1 Hardware implementation

All sensors are installed directly on the 4WD platform to ensure high mobility and reliability of autonomous navigation within the closed workspace. The main navigation task is to provide unhindered movement in the forward direction. For leading lines and objects detection, the computer vision system includes 1080p high resolution monocular CMOS camera with a 160° viewing angle and a variable focal length based on the chip OV5647. The data from 3-axis accelerometer and gyroscope of the MPU-6050 module are used to get a stabilized video stream and to hold the camera in a horizontal position. To avoid collisions in unpredictable situations such as incorrect objects recognition of the workspace, the wheeled platform has an additional ultrasonic distance sensor HC-SR04, which has no “blind zones” in the front plane with a measuring range from 0 to 150 cm and with an accuracy of 0.3 cm.

Estimation of the workspace, due to the dynamic characteristics of the wheeled platform and surrounding objects, requires the rapid processing of video data received from the camera. A single-board computer Raspberry Pi 3 provides enough computational power for processing video stream and to control engines and servos. Raspberry Pi 3 implements standard interfaces for wire and wireless communication for remote control, and also supports high-level programming languages. To provide maneuverability, the mobile platform uses a classic steering system. Taking into account small dimensions and model weight, a small SG90 servo actuators are used for steering the platform, providing a sufficient starting torque of 2 g/cm. To achieve required dynamical characteristics of the platform authors used DC motor HRK-370SH, which provides a torque of 79.6 g/cm at a starting current up to 28 A. As a driver we selected VNH2SP30 which generates power signals to the drive system. Alignment of sensors and elements of the control system is made with taking into account the minimum length of wires connections and the usability to work with charging and programming interfaces. Creating a control system prototype for further scaling to a physical AGV needs to take into account the type of wheelbase of the real system. Therefore, wheelbase was chosen from ready-made solution, which provides similar adhesion to the surface and the area for the placement of the control, actuators, sensors and auxiliary elements. An independent cushioned suspension gives ability to reduce the vibrations that affect camera and MPU to the acceptable level. The rigid frame, was designed in KOMPAS-3D and SolidWorks and finally PLA printed, has good weight balance thanks to effective arrangement of the functional elements and battery pack. The communication and structural possibilities to plug in and fast modification of sensors, power and control units in 4WD platform design

was taking into account as well.

The final design of the assembled control unit is shown on Figure 1.

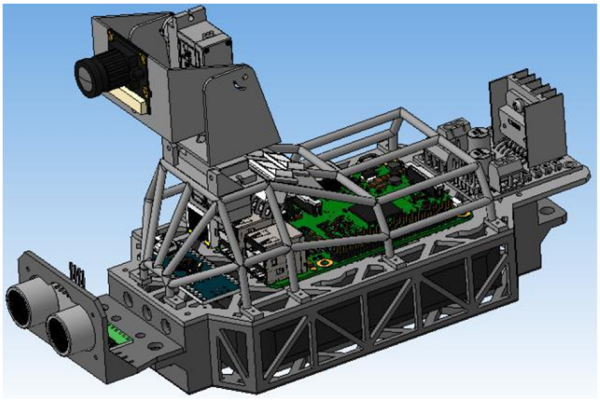


Fig. 1. The general view of control unit with the placed components.

The electrical circuit uses TWI to connect Arduino Nano and MPU-6050 to Raspberry Pi 3. Driver VNH2SP30 connection to Arduino Nano uses standard PWM driver control. Arduino Nano gets power supply through the USB port.

The electrical scheme of connecting the control unit to the drive mechanisms of the wheelbase and sensors is shown on Figure 2.

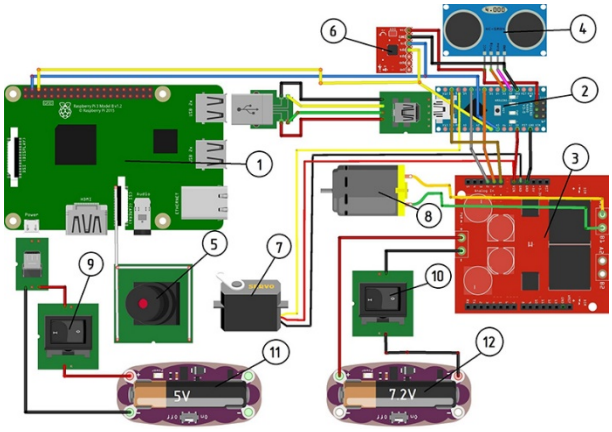


Fig. 2. The electrical scheme of control units and peripheries connections.

The scheme has following items: Raspberry Pi 3 single-board computer (1); Arduino Nano to control driver and ultrasonic sensor (2); VNH2SP30 driver for the main engine (3); HC-SR04 ultrasonic sensor (4); Raspberry PI OV5647 camera (5); MPU-6050 module with 3-axis accelerometer and gyroscope (6); SG90 servomotor of the steering axle (7); HRK-370SH electric motor of the main movement (8); Raspberry Pi 3 power button (9); HRK-370SH power supply button for the electric motor (10); battery 5 V, 8800 mAh for power supply of electronic circuits (11); Battery 7.2 V, 1500 mAh for main power supply (12).

4.2 Control implementation

For safe motion stop of the 4WD platform, the control system implements the braking mode by calculating of the speed variation which is inversely proportional to the residual distance to the obstacles. The proportional (P) control implements the rigid gear of a controlled value through feedback over distance, determined by the following equation:

$$\mu = K_p \cdot \Delta U_s, \quad (1)$$

where μ – is the influence of the regulator on the end-effector (EF) by actuator; ΔU_s – is the error signal from the comparison element (CE).

The transfer coefficient K_p is numerically equal to EF offset when the output value is changed to the unit of measurement. To calculate the P-gain for 8-bit PWM, the control signal range varies from 0 to 255. To overcome the dead zone determined by the forces of dry friction in the wheelbase and transmission, the range of PWM control signals is experimentally defined and narrowed to an interval of 130 to 255.

After the physical experiment, safety zone that guarantees obstacles avoiding by taking into account the massive inertia characteristics of the current platform was determined at the distance of 150 cm. The braking system is calibrated to this level as a reference point to start braking process. Parameter estimation of braking process that is given to the driver is shown below:

1. To set the braking system reference point we subtract the current distance to the obstacle archived by the ultrasonic sensor from safely distance:

$$D_{dist}=150–D_{deadzone}, \quad (2)$$

where D_{dist} – the measured distance to the obstacle in the sensor measurement system; $D_{deadzone}$ – sensitivity sensor threshold corrected to the safety shift of platform.

2. The driver PWM parameter calculated as:

$$P_{pwm}=255–(255\cdot(D_{dist}/150)), \quad (3)$$

where $P_{pwm,}$ – is the calculated value of the PWM parameter for main actuator power control.

The need to simplify the information contained in the video stream from the high-resolution camera requires filtering. The Open Computer Vision Library (OpenCV) has an application level program interface (API), compatible with high-level programming language and provides interoperability for the implementation of computer vision system [13]. The camera's maximum resolution is 2592 × 1944 pixels. For 2 lines navigation task with stripes wider than 5 cm, the experimentally estimated low threshold of image area is 800 × 600 pixels to operate. Image processing and filtering takes place at several stages [14, 15]. The recognition technique begins from preliminary processing for better markers color detection and vectorization of the input image for mathematical calculations. The camera calibration needs manual tuning at the beginning in order to be able to take into account non-uniform light and color temperature. The color transformation converts blue-green-red color scheme (BGR) to hue-saturation values (HSV) to create the appropriate binary mask for target color of leading lines. Implementation of the Hough transformation [15]

helps to combine the lines to polygons formation.

The next step is to reconstruct the conditions of real workspace to analyze the efficiency of library techniques and navigation parameters. The non-uniform light leads to deviation of contrast of the images, there are false lines for the matching of floor plates. The glare of light prevents interference in leading lines detection, the marking lines have a wavy shape and a heterogeneous structure. After the initial processing and filtering of the source video, the procedure generates an array of coordinate pairs of two points (x_1, y_1, x_2, y_2) of the recognized polygonal segments of lines. To determine the actual lines, there is a pixel analysis of the fragments of the polygon lines. Each leading line is split to pixels by searching the line neighboring points coordinates. Using Python language [14], the pixel to line normalization is performed using eachPixelOfLine function. The pixel cropping function of the line is implemented with the use of the yield generator. This function provides more efficient use of memory through the processing of one line in one pass and increases the productivity of the analysis. After obtaining the points coordinates, the nearest points to the center of the lines can be found by using the get TheNearestLine function. The points coordinate values in the processing are not constant and Kalman filter [12, 14] helps to average them.

To navigate the 4WD platform, we need to find a horizontal center between the lines, which will be the reference for the adopted steering control. The center estimation is based on the following equation:

$$P_C = (P_L - P_R / 2) + P_L, \quad (4)$$

where P_C – the calculated horizontal center between the recognized lines; P_L – the nearest left point; P_R – the nearest right point.

The information about difference between the horizontal center between lines and physical camera orientation relative to the wheels helps to orient the platform on the track, using the PID-control to steer.

The general algorithm of the 4WD platform control system is shown on Figure 3.

After initializing Raspberry PI 3 and Arduino (downloading the created program, importing libraries, defining global variables) the boards verify access to the video stream. Each frame in iteration cycle is undergoing preprocessing. The image is transformed into colorless format for a more efficient procedure of locating leading lines and using openCV library. To achieve the reference point for steering axis the procedure detects center point of tracking path. After implementation of procedures for finding the closest lines the Kalman filter helps to average the central points coordinates. On the next step executes gathering of the actual data for steering, the program checks access Arduino Nano serial interface and transmits the data. During data transition, the terminal activates Arduino Nano that controls driver and ultrasonic sensor connections. To work with peripherals the board initiates the base configuration, variables and libraries. The program calculates the wheel angle and applies it to the driver of steering servomotor. An emergency brake system based on an ultrasonic sensor is triggered if the distance to the obstacle is less than 30 cm. In this case, the 4WD platform does not move until the obstacle is present. If the distance to the obstacle is in the range of 30 to 150 cm, the speed of the wheeled platform varies in proportion to this distance by P-control.

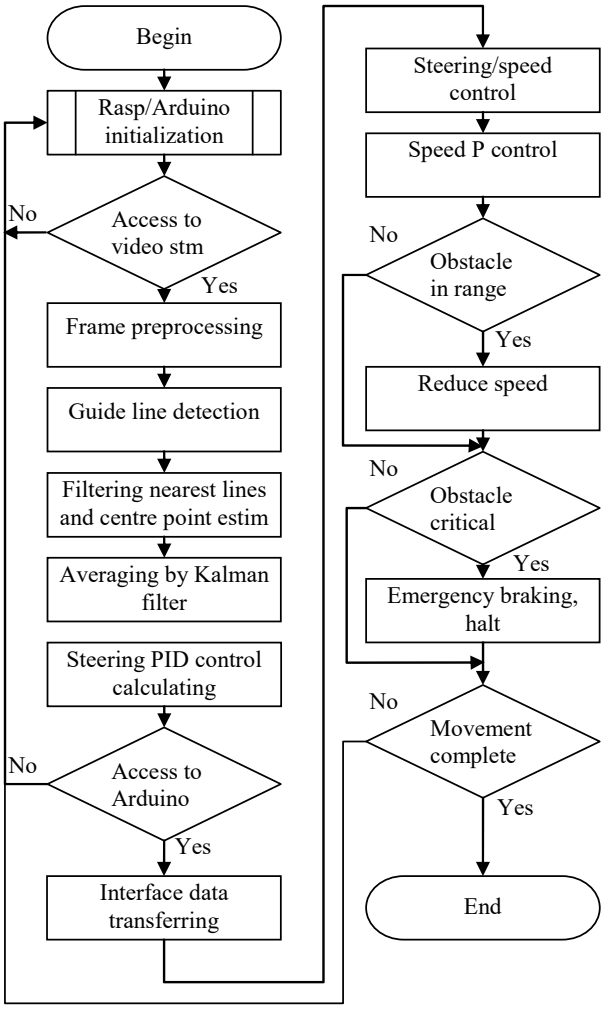


Fig. 3. The general algorithm of the 4WD platform control system.

The 4WD platform navigation software was developed using ST programming language Python3 (for Raspberry PI) and C (for Arduino Nano). Software for Raspberry Pi was developed in JetBrains PyCharm IDE [14]. Searching the artificial leading lines is procedural, with a call to external events. Arduino IDE environment uses procedure submissions with objects' environment model and abstract variables to work with system control like direction, speed, steering angle and brake.

5 Experiment

The experimental part of the study is to conduct a natural experiment, which involves the distance movement of 4WD platform along a straight path. Moreover, the nature of surface illumination and the surface itself are complex in terms of reflective properties. The recognition technique involves the use of a pair of green navigation lines, the distance between which is greater than the width

of the wheelbase.

The distance between green and white crosses determines the difference in camera and wheel orientation that must be compensated on the course. The program timer helps to synchronize the main program loop with Arduino response time. To obtain the position of 4WD platform on the path, MPU-6050 accelerometer module is used to get acceleration data in X-Y horizontal plan by the following methods [9-11].

The experimental results of processing the input stream of workspace are shown on Figure 4 and Figure 5.

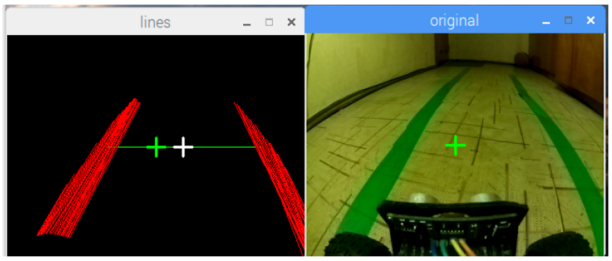


Fig. 4. The platform shifts to the left.

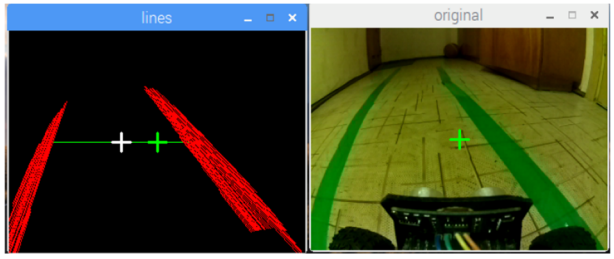
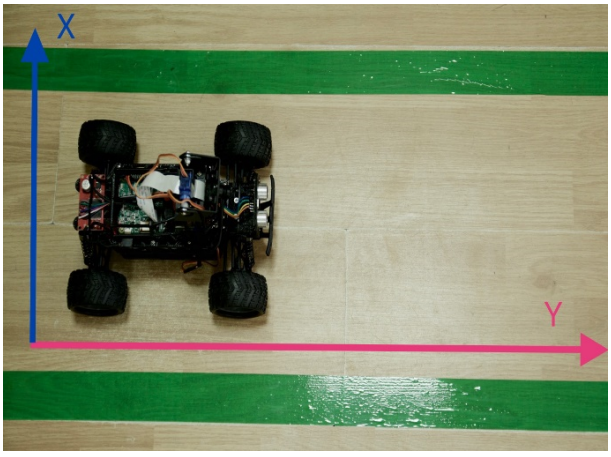


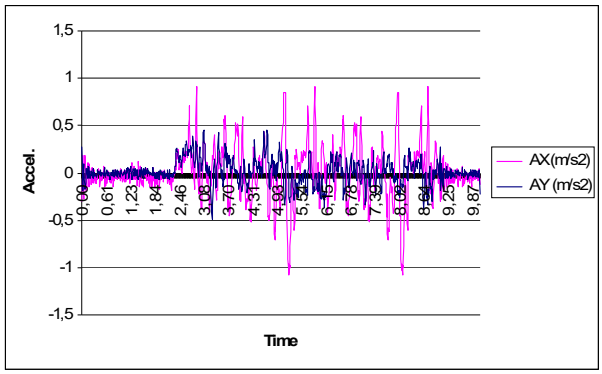
Fig. 5. The platform shifts to the right.

The source datasheet contains discreet time and acceleration along X and Y axes. After double integration it is possible to calculate velocity and relative position of wheeled platform. The result of steering control towards linear path, obtained with MPU-6050 accelerometer module for X-Y plan, is shown on Figure 6.

Reflected light near the starting position distorts the right guide line and steering control shifts to the right. At this case, the maximum deviation along the X axis reaches 12 cm (4WD platform does not cross the track border). Measured with the accelerometer relative distance is 107 cm which is close to planned 100 cm taking into account instrumental and computational errors.



a)



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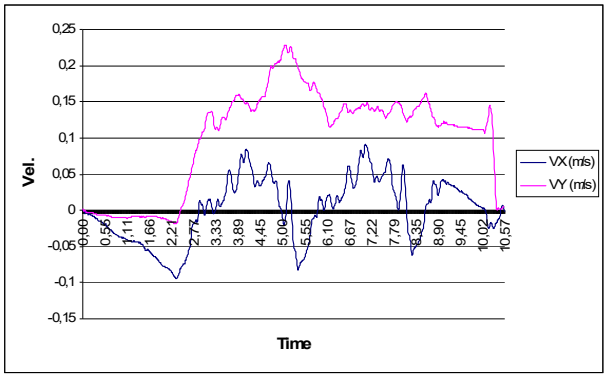

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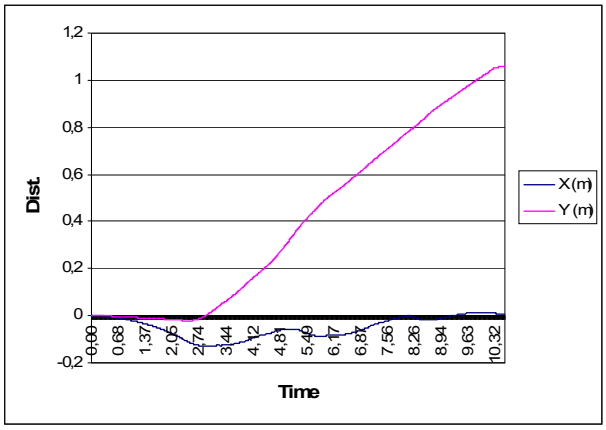

d)

Fig. 6. Experimental results of tracking the linear path:
a) Initial position of 4WD platform; b) auxiliary along X and Y axis; c) velocity along X and Y axis; d) path deviation along X and Y axis.

6 Discussion of research results

The AGV recognition system, built on a computer vision, gives more flexible approach to planning and maneuvering. The reliability of its use depends on the possibility of an error-free evaluation of the working area and consideration of possible situations in the control algorithms. Using a computer vision system allows to evaluate a large number of workspace options for navigation.

The operation of vision sensor is influenced by the various environmental conditions on which the result of recognition depends. One of the main problems of recognition is the uniformity of illumination and the

presence of reflecting surfaces. Even in artificial lighting conditions, the brightness level changes as a result of the appearance and disappearance of objects with different reflecting and light-absorbing properties. Extra artificial route marking, such as colored guide lines and markers, greatly simplifies the navigation task, as described in the study. The proposed approach, calculations and experimental studies of small 4WD platform show the possibility of fast navigation along the guide lines.

The limitations inherent in this study are the reflection of light leads to a mistake in steering the platform. However, as shown by the results of experimental part, the system still remains robust along the marked path, and the response of the control system is less than 0.2 seconds.

The prospect of further research is the realization of the maneuvering task around obstacles of complex geometry using object tracking by a camera with stabilization on the road using an accelerometer, as well as servicing many routes with visual marking.

7 Conclusion

1. The proposed 4WD platform provides autonomous movement and maneuvering using the steering system on a flat surface. The maximum radius of front wheels steering was 9 cm at a maximum speed of 0.8 m / s, which characterizes the high dynamics and maneuverability of navigating using guide lines.
2. The hybrid control system implements a terminal safety connection between the Raspberry PI and the Arduino Nano, allows extreme braking beyond the main control based on computer vision.
3. Implemented mathematical models and algorithmic-software implementation are intended to simplify the processing of data in the navigation direction along the guide lines. Estimating the lines perspective rate by computer vision allows additional control the speed on the way.
4. During experimental studies of autonomous driving stability on the road, the influence of uneven illumination and glare surfaces of the guide lines was estimated.

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Information and measurement system of weapon stabilization parameters based on precision piezoelectric sensitive element

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Abstract. The structure and principle of information and measurement system performance of weapon stabilization are described. Established, that the classical stabilization system consists of a stabilizing platform of the sensitive element (or block of sensitive elements), defining the absolute angle of platform α rotation, the sensing element output signal amplifier, engines and tachometers. The classical system of indirect stabilization is reviewed, its mathematical description is made. A new precision sensitive element for the information and measurement system of weapon stabilization is suggested, the principle of its performance is introduced. Constructive methods of measurement accuracy improvement in the new sensitive element are analyzed. A simulation of the new sensitive element performance influenced by the external disturbances is carried out.

1 Introduction

The Sustainable Development Strategy "Ukraine 2030" defines the purpose, vectors of movement, roadmap, priority and indicators of adequate defense, socio-economic, organizational, political and legal conditions of formation and development of Ukraine. The main purpose of the reform of the national security and defense is to improve the defense of the state, reforming the Armed Forces of Ukraine and other military formations of Ukraine in accordance with modern requirements and the experience gained during the counterterrorist operation and development of defense industry to maximize meet the needs of the army. The Armed Forces of Ukraine, priority should be given full renovation of structures, ranging from governments and ending with the staff list and units, as well as optimization of systems and standards support, the introduction of new models of weapons and military equipment, revision of tactics and strategies to meet the requirements of today.

One of the trends in the development of modern combat vehicles fire control systems is the development of a more effective weapon stabilizer with high precision parameters contributing to the increase of the military combat vehicle power and the survivability of the "crew-machine" system. In this regard, the analysis of the development of modern weapons stabilizers is an urgent task.

Relating to this, the analysis of the contemporary weapon stabilizers development is a relevant issue. Technically, the stabilizer is a set of sensors and a computing complex connected to the gun drive. Based on the sensor performance, the parameters of the platform displacement are determined and the gun actuator is provided with control commands compensating the deviation.

In the article, an automatic control system is considered as a system of stabilization ensuring the maintenance of certain angular tower orientation in relation to the coordinate system the axes of which in a certain way are oriented in space. This coordinate system is a reference one. Depending on the specific task, this may be, for example, an inertial coordinate system or a system the axes of which are directed vertically to the moving object.

2 Literature review

Today, the development of new information and measurement weapon stabilization complexes of its sensitive elements is performed by scientists of National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Zhytomyr Polytechnic State University in cooperation with the public joint-stock company "Scientific and Production Association "Kyiv Automation Plant" [1].

Therefore, the relevant scientific and technical issue today is to improve the accuracy of the weapon stabilization complex.

In [2], an analysis of the current armored vehicles condition in Ukraine is performed. The effectiveness of new weapon stabilization complexes development is explained.

In [3] the structure of the pointing and armor

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stabilization system of light armored vehicles with a neural network controller is described. However, the point of using a neural network approach to compensate the instrumental errors has not been considered.

In [4-5], it is proposed to use a coriolis vibrating gyroscope as a sensitive element of the stabilization system. The make-up and principle of the well-known navigation complex strike- and vibroprotection of the light armored vehicles system performance is analyzed. However, there are no suggestions to improve the system technical characteristics, mathematical model and errors of the system sensitive elements analysis.

In [6], schematic models were constructed and piezoelectric transducers with additional electrical oscillating circuits to be used as a sensitive element of a weapon stabilizer were simulated. The use of models like that allows the use of applications to evaluate the characteristics and prediction of piezoelectric converters parameters and performance modes. However, the results obtained cannot be used as evidence that a sensor of such a design is more accurate than its counterparts, since no two-channel measurement error compensation schemes are considered.

Article [7] describes the use of MEMS technologies to develop sensitive elements for measuring acceleration and vibration.

The purpose is to develop a new precision sensitive element of the information and measurement system of the weapon stabilization parameters.

3 The structure of information and measurement system of weapon stabilization

The oscillations of the mobile military equipment hull are random and never stop during its movement. The amplitudes of the angular oscillations have quite high frequencies. This leads to significant movement of the target mark relative to the target and does not allow the gun pointer to hold it even with the most advanced actuators.

The oscillations in the longitudinal plane changing the angle of the gun elevation, and angular oscillations in the horizontal plane, changing the angle of horizontal guidance, have the greatest influence on the firing accuracy. They lead to considerable dispersion of shells and bullets.

Transverse angular oscillations causing the gun to tilt have less impact, but grow with the firing distance.

First and foremost, these factors cause the raise in pointing errors, increasing by 10–30 times when firing from the move compared to the stationary fire.

The classical stabilization system consists of a stabilizing platform of the sensitive element (or block of sensitive elements), defining the absolute angle of platform α rotation, the sensing element output signal amplifier, engines and tachometers.

The block diagram of the classical indirect stabilization system is presented in [8-9] and is shown in Fig. 1, where SE is a sensitive element; A – amplifier; E – engine; R – reducer; P is a stable platform; $W_1(p)$ and $W_2(p)$ are the transfer functions of the amplifier units together with the correction means; $X(p)$ is the transfer function of the signal chain by the angle derivatives of the platform rotation α_2 with respect to the oscillating object $\lim\limits_{p\to 0} X = 0$; $K(p)$ is the transfer function of the signal chain by the oscillation angle derivatives θ, $\lim\limits_{p\to 0} K = 0$.

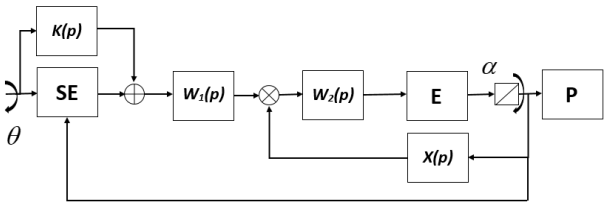

Fig. 1. Block diagram of the weapon indirect stabilization.

In [1] an example of a stabilization system that is recommended to be used as a part of aviation gravimetric systems is highlighted. In this system, the horizontal stabilized platform (GSP) has two linear accelerometers and actuators represented by special engines.

The stabilization system functions in the following way: the output signals of the linear accelerometers f_y, f_x installed on a GSP oriented in a geographical coordinate system, the sensitivity axes, respectively forwarded to north and east, will have the form [8]:

$$f_x = -(2\dot{r}\dot{\phi}_c + r\ddot{\phi}_c)\cos\chi + (\ddot{r} - r\dot{\phi}_c^2)\sin\chi - 2r\omega_E\dot{\lambda}\cos\phi_c\sin\phi - r\dot{\lambda}\cos\phi_c\sin\phi + Qg; \quad (1)$$

$$f_y = 2r\dot{\phi}_c\omega_E\sin\phi_c + 2r\phi_c\dot{\lambda}\sin\phi_c - -2\dot{r}\dot{\lambda}\cos\phi_c - r\ddot{\lambda}\cos\phi_c - 2\dot{r}\omega_E\cos\phi_c - vg, \quad (2)$$

where Q, v are the angles between the normals to the ellipsoid and geoid respectively in the meridional cross section and in the cross-sectional plane perpendicular to the meridian plane;

ϕ, ϕ_c – respective geographical and geocentric latitude;

χ – deviation from the vertical;

λ is the longitude;

g is the acceleration;

r is the radius of the location;

ω_E is the Earth rotation speed.

The received signals are directed to the onboard computer where the control signal is emerging, then coming to the engines that further adjust the GSP to zero.

If the GSP is set exactly in the vertical position, the horizontal components of the gravity acceleration are equal to zero. Considering that $Q_g = -vg = 0$, the components the onboard computer will compensate are the following:

$$f_x \Rightarrow 0 = 2r\omega_E\dot{\lambda}\cos\phi_c\sin\phi - r\dot{\lambda}\cos\phi_c\sin\phi; \quad (3)$$

$$f_y \Rightarrow 0 = 2r\dot{\phi}_c\omega_E\sin\phi_c + 2r\phi_c\dot{\lambda}\sin\phi_c - -2\dot{r}\dot{\lambda}\cos\phi_c - 2\dot{r}\omega_E\cos\phi_c. \quad (4)$$

Neglecting the components of the second order and taking the deviation from the vertical equal to zero, there we have:

$$f_x = -r\ddot{\phi}_c; \quad (5)$$

$$f_y = -2r\dot{\lambda}\cos\phi_c. \quad (6)$$

If case each of the signals f_y and f_x is multiplied by r^{-1}, integrated and multiplied by (-1), then at the output of the corresponding channels we get $\dot{\phi}$ and $\dot{\lambda}\cos\phi$. The signal $\dot{\phi}$ will be used to control the GSP with respect to the x axis facing north, and the signal $\dot{\lambda}\cos\phi$ – to control the y axis facing east.

In [10] both new high-precision piezoelectric and capacitive, string, gyroscopic sensitive elements are described. They can be used as parts of a stabilization system having their advantages and disadvantages. The use of the dual-channel method to eliminate the effect of instrumental errors on the accuracy of the conversion device is described.

Nowadays, the investigation of piezoelectric sensitive elements accuracy improvement is advanced. The new precision piezoelectric sensing element being more accurate than the already existing has been developed by the article authors.

3.1 Signal conversion in piezoelectric sensing element

The analysis of the signal conversion structural diagram in the piezoelectric element is suggested:

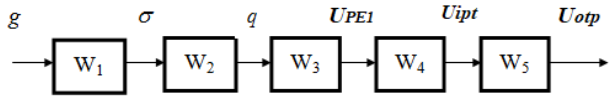

Fig. 2. Block diagram of direct signal conversion in piezoelectric sensing element.

Block W_1 corresponds to the conversion of acceleration g, acting on PE, into mechanical stress σ. This mechanical stress is numerically equal to the force G, per unit cross-sectional area of PE. If the mechanical stress is constant over the entire cross-sectional area PE S, then $\sigma = G/S$, therefore [11] (Fig. 2):

$$W_1 = \frac{\sigma}{G} = \frac{G}{S}\cdot\frac{1}{G} = \frac{1}{S}. \quad (7)$$

Block W_2 corresponds to the conversion of mechanical stress σ into charge q on PE electrodes:

$$W_2 = \frac{q}{\sigma} = \frac{d_{ij}\cdot\sigma\cdot S}{\sigma} = d_{ij}S \quad (8)$$

where d_{ij} – piezomodule.

Block W_3 corresponds to the conversion of charge q into the voltage of U_{PE} at PE electrodes. The transformation of this type is reflected in Fig. 3. diagram.

In accordance with the current I scheme in Fig. 3 there can be written:

$$I = \frac{dq}{dt} = \frac{U_{PE}}{R_{PE}} + C_{PE}\frac{dU_{PE}}{dt}. \quad (9)$$

If we accept zero initial conditions, then the solution of the differential equation will the following:

$$U_{PE} = \frac{q}{\left(1+\frac{1}{jwR_{PE}C_{PE}}\right)C_{PE}}. \quad (10)$$

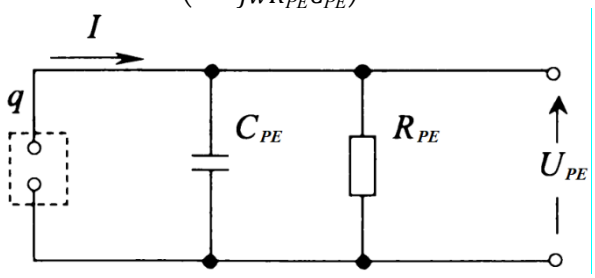

Fig. 3. Equivalent W_3 link conversion scheme.

Hence the transfer function will be:

$$W_3 = \frac{U_{PE}}{q} = \frac{q}{q\cdot(1+\frac{1}{jwR_{PE}C_{PE}})C_{PE}} = \frac{1}{(1+\frac{1}{jwR_{PE}C_{PE}})C_{PE}}. \quad (11)$$

However, given the large value of R_{PE}, it is possible to accept:

$$W_3 = \frac{1}{C_{PE}} \quad (12)$$

Block W_4 describes the process taking place when the voltage on PE (transfer U_{PE} in the circle U_{ipt}). Its transfer function corresponds to the transfer function of the modifying differential link, where R_{BX} – input voltage amplifier resistance. Given the high PE resistance, the input of the amplifier is represented only by the resistance R_{ipt}.

$$U_{ipt} = (I_1 + I_2)\cdot R_{ipt}, \quad (13)$$

$$I_1 = C_{PE}\frac{dU_{C_{PE}}}{dt}, \quad (14)$$

$$I_2 = \frac{U_{C_{PE}}}{R_{PE}}. \quad (15)$$

In the result of substitution (14-15) in (13) we obtain:

$$U_{ipt} = \left(C_{PE}\frac{dU_{C_{PE}}}{dt} + \frac{U_{C_{PE}}}{R_{PE}}\right)R_{ipt}. \quad (16)$$

According to Kirchhoff's law:

$$U_{C_{PE}} = I_2 R_{PE} = U_{PE} - U_{ipt}. \quad (17)$$

Substituting (17) into (16) obtain:

$$U_{ipt} = C_{PE}R_{ipt}\frac{d(U_{PE}-U_{ipt})}{dt} + \\ + \frac{R_{ipt}}{R_{PE}}(U_{PE}-U_{ipt}). \quad (18)$$

For further calculations we introduce the coefficient:

$$\varepsilon_R = \frac{R_{PE}+R_{ipt}}{R_{ipt}} \quad (19)$$

Divide expression (18) by the coefficient ε_R:

$$\frac{U_{ipt}}{\varepsilon_R} = \frac{C_{PE}R_{ipt}}{\varepsilon_R}\cdot\frac{dU_{PE}}{dt} - \frac{C_{PE}R_{ipt}}{\varepsilon_R}\cdot\frac{dU_{ipt}}{dt} + \\ + \frac{1}{\varepsilon_R}\frac{R_{ipt}}{R_{PE}}U_{PE} - \frac{1}{\varepsilon_R}\frac{R_{ipt}}{R_{PE}}U_{ipt}. \quad (20)$$

Group the members of equation (20) and get rid of the denominator R_{PE}:

$$\frac{R_{PE}U_{ipt}}{\varepsilon_R} + \frac{R_{ipt}}{\varepsilon_R}U_{ipt} + \frac{C_{PE}R_{ipt}R_{PE}}{\varepsilon_R}\cdot\frac{dU_{ipt}}{dt} = \\ = \frac{C_{PE}R_{ipt}R_{PE}}{\varepsilon_R}\cdot\frac{dU_{PE}}{dt} + \frac{R_{ipt}}{\varepsilon_R}U_{PE}, \quad (21)$$

$$U_{ipt} + \frac{C_{PE}R_{PE}}{\varepsilon_R}\cdot\frac{dU_{ipt}}{dt} = \frac{1}{\varepsilon_R}\left(C_{PE}R_{PE}\cdot\frac{dU_{PE}}{dt} + U_{PE}\right). \quad (22)$$

Denote the time constant $\tau=R_{PE}C_{PE}$. In the result of the time constant by equation substitution (22) and the Laplace operator introduction, we obtain:

$$\left(1 + \frac{\tau}{\varepsilon_R}p\right)U_{ipt} = \frac{1}{\varepsilon_R}(1+\tau p)U_{PE}. \quad (23)$$

The W_4 transfer function will be:

$$W_4(p) = \frac{U_{ipt}}{U_{PE}} = \frac{1}{\varepsilon_R}\frac{1+\tau p}{1+\frac{\tau}{\varepsilon_R}p}. \quad (24)$$

The W_5 corresponds to the voltage amplifier transmission characteristic [11], behaving as a first order inertial link:

$$W_5(p) = \frac{K_{VA}}{1+p\tau_{VA}}, \quad (25)$$

where K_{VA} – coefficient of the operational amplifier gain; τ_{VA} – time constant.

However, given the operation of the converter mainly in the narrow frequency range, the transmission characteristic can only be equated to the gain:

$$W_5 = K_{VA}. \quad (26)$$

Therefore, the transfer function of the signal in PE will be:

$$W(p) = W_1W_2W_3(p)W_4(p)W_5 = \\ = d_{ij}\cdot\frac{1}{C_{PE}}\cdot\frac{1}{\varepsilon_R}\frac{1+\tau p}{1+\frac{\tau}{\varepsilon_R}p}\cdot K_{AV}.$$

However, PE has a tendency to discharge, so a negative feedback loop must be added to the direct signal conversion scheme.

3.2 Three-coordinate piezoelectric sensitive element

Increasing the measurement accuracy of the new precision sensitive element of the stabilization system is ensured by the fact that for each of the measurement axis *Oz*, *Ox* and *Oy* on the GSP a sensitive element is installed. The sensitive element is made of two channels, each of which has one piezoelectric element being identical. The inertial masses are attached to the piezoelements piezo-plates bottom of one channel and to the top of the piezoelements piezo-plates of the second channel. The first channel piezoelectric element of each sensitive element operates on the basis of extensional strain, and the second channel piezoelectric element is based on the compression (Fig. 4).

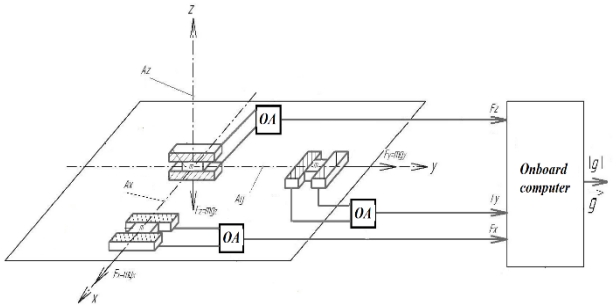

Fig. 4. Block diagram of the precision piezoelectric sensitive element.

The three-coordinate sensitive element operates as follows: the piezoelectric elements of both channels of the three sensitive elements *Az*, *Ax*, *Ay*, located along the axes *Oz*, *Ox*, and *Oy*, are respectively accelerated. Also, the vertical acceleration of the aircraft and instrumental errors, in the result of residual non-identity of the same piezoelectric and mass structures, as well as in the result of changes in temperature, humidity and ambient pressure, affect each of the measurement axes.

If we use the algorithm of the two-channel measurement scheme performance for the two-channel piezoelectric element *Az*, *Ax*, *Ay,* we will receive as the on-board computer inputs 13 three signals having double values $2g_z$, $2g_x$, $2g_y$ with no vertical plane acceleration and instrumental errors value resulting in the influence of residual non-identity of identical piezoplates structures and masses, the influence of temperature change, humidity and ambient pressure. These signals are added to and amplified in the performance amplifiers OP10, OP11, OP12 and are fed to the on-board computer 13, determining:

– full acceleration vector:

$$\vec{g} = \vec{g_x} + \vec{g_y} + \vec{g_z}; \quad (27)$$

– full acceleration module:

$$|g| = \sqrt{(2kmg_x)^2 + (2kmg_y)^2 + (2kmg_z)^2} = \\ = 2km\sqrt{g_x^2 + g_y^2 + g_z^2}, \quad (28)$$

where *m* is the inertial masses 7, 8, 9 in each piezoelectric element;

k – piezoelectric constant being the same for all piezoelectric elements because of their identity.

The onboard computer takes control of the required calculations resulting in sending a control signal to the GSP engines. Also, the onboard computer output will get the full vector value and the full acceleration module, having no instrumental errors effect in the result of the

residual non-identity influence of the same piezoelectric and mass structures, the influence of temperature changes, humidity and ambient pressure.

3.3 Using dual-channel method

The measurement accuracy improvement is possible due to use of the dual-channel method. The method is explained by the drawing, depicting a structural diagram of a piezoelectric sensitive element (Fig. 5) [10].

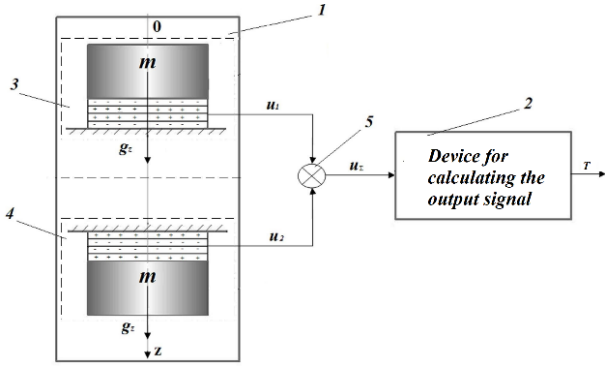

Fig. 5. Block diagram of the two-channel piezoelectric sensitive element.

The sensitive element 1 is made up of two channels, with the each one having a piezoelectric element. The piezoelectric elements of both channels are identical and are represented by piezo-plates and inertia mass, fixed on top of each other. The piezoelectric element 3 of one channel the piezo-plates of which are placed downwards, and the piezoelectric element 4 of the other channel, the piezo-plates of which are located upwards. The piezo-plates outputs of both channels are connected to the inputs of the adder 5, the output of which is connected to the input of the output signal calculation device 2.

The piezoelectric elements of both channels are affected by acceleration g, vertical acceleration $\Delta\ddot{z}$ and instrumental errors Δi resulted in the effects of residual non-identity of the same piezoelectric and mass structures, the influence of temperature changes, humidity and ambient pressure. If all these effects are exposed on the *Oz* axis of the new sensitive element considering that the piezoelement 3 of one channel compresses and the piezoelement 4 of the other channel stretches, we obtain [1]:

$$u_1 = k(mg + m\Delta\ddot{z} + \Delta i), u_2 = k(mg - m\Delta\ddot{z} - \Delta i),$$

where u_1 – the output electric signal of one piezoelement channel; u_2 is the output electric signal of the other piezoelement channel; m is the inertia mass weight in each of the channel; k is the piezoelectric constant.

The output electric signals u_1 and u_2 of both piezo-plates channels are summed up in the adder 5:

$$u_\Sigma = u_1 + u_2 = 2kmg \qquad (29)$$

where u_Σ is output adder 5 signal.

The output adder 5 signal is fed to the output calculating device where it is calculated over a certain period of time. In the result, we obtain the output signal of the output signal calculation device of the sensitive element, containing the double valid signal. It completely has no such measurement errors caused by the effects of vertical acceleration and instrumental errors.

4 Simulation of the operation of the sensing element

In [10], a mathematical model of a three-coordinate sensitive element of the weapon stabilization information-measuring system is presented. Software for its performance modeling under the influence of external perturbations is developed (Fig. 6).

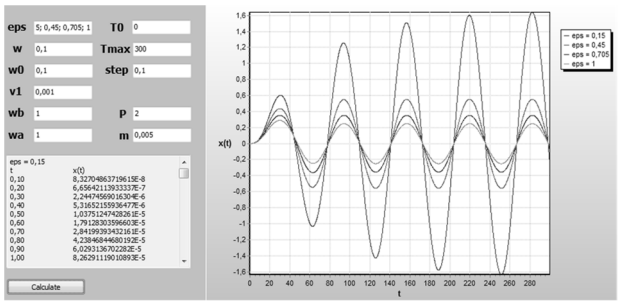

Fig. 6. Interface of the program for developing the sensitive element performance under the influence of the external perturbations.

Graphs of the PG output signal change for different perturbation frequency ω, the damping coefficient ξ and the amplitudes of vibrational acceleration perturbation are obtained. In the result of the performed digital simulation analysis, it is established that (Fig. 7-8):

– when the disturbance frequency is equal to the natural frequency of the sensitive element, the main resonance happens disappearing at $\xi = 0.705$;

– at perturbation frequencies less than the natural frequency of the sensitive element, the output signal is not distorted (subharmonic oscillations are established);

– at perturbation frequencies higher than the natural frequency of the sensitive element and $\xi \leq 0{,}45$ the output signal is distorted (runout happens), that is why it is to the point to increase ξ.

5 Conclusions

The analysis of the structure and performance principle of the information and measurement system of weapon stabilization, which can be installed on light armored vehicles, is made. The simplest system of indirect stabilization is reviewed; its mathematical description is made. The new precision sensitive element for the information and measurement system of weapon stabilization is suggested. The performance principle of it is introduced. Constructive methods for the new sensitive element measurement accuracy improvement are analyzed. A simulation of the new sensitive element performance under the influence of external perturbations is carried out.

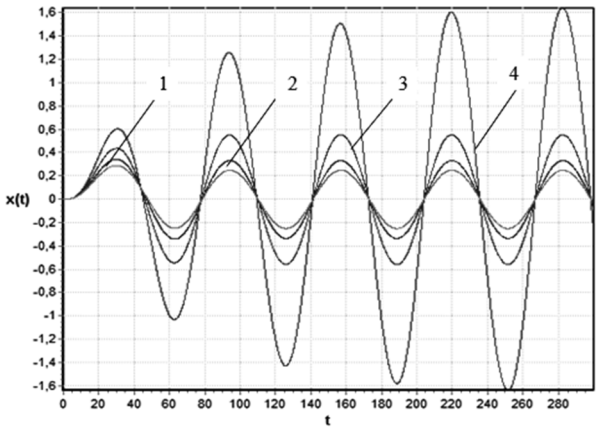

Fig. 7. A typical graph of the amplitude of the output signal $x = x'(t)$, $\omega = \omega_0 = 0.1$ rad/s: 1 – $\xi = 1$; 2 – $\xi = 0.705$; 3 – $\xi = 0.45$; 4 – $\xi = 0.15$.

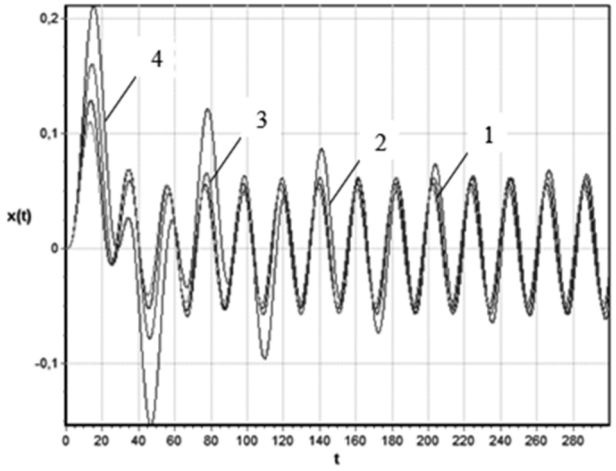

Fig. 8. A typical graph of the amplitude of the output signal $x = x'(t)$, $\omega = 3\omega_0 = 0.3$ rad/s: 1 – $\xi = 1$; 2 – $\xi = 0.705$; 3 – $\xi = 0.45$; 4 – $\xi = 0.15$

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Information and measurement system for determining the acceleration of gravity based on a ballistic gravimeter with a two-dimensional video system

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Abstract. The aim of the sustainable development strategy is to introduce European standards of living in Ukraine and Ukraine's leading position in the world. Active development is observed in information and measurement systems. The article provides a refined mathematical model of the new ballistic laser gravimeter. The composition and structure of the main errors of the ballistic laser gravimeter are given. The main errors of the ballistic laser gravimeter are calculated and estimated. The computer behavior of ballistic laser gravimeter behavior for the most unfavorable resonance modes for different ratios of disturbance values and proper ballistic laser gravimeter parameters is performed. It is suggested to use digital video as a medium of measurement information in the new ballistic laser gravimeter.

1 Introduction

Today, Ukraine needs to become a state with strong economies and advanced innovations. To do this, first of all, it is necessary to restore macroeconomic stability, to ensure sustainable economic growth in an environmentally sustainable way, to create favorable conditions for economic activity. Active development is also observed in information and measurement systems. Modern systems must meet both the technical and environmental requirements of humanity.

Measuring the absolute value of gravity acceleration with high accuracy is necessary for solving a wide range of scientific problems: determining the shape of the Earth, constructing models of motion of deep masses, predicting earthquakes, inventing deep density inhomogeneities, finding minerals, and others. Gravimeters are used to determine *g*. Among them, the most well-known for terrestrial measurements are ballistic laser gravimeters (BLG).

It is known that the use of computers as simulation devices can: reduce, and in some cases completely eliminate the need for physical experiments with real devices, greatly reduce the time, improve productivity, accuracy of research all this has a significant economic effect.

The article [1] describes an advanced gravimetric system for low flow rates that was developed by the National Institute of Metrology of Japan (NMIJ) to perform the method of flight-start and stop calibration. However, there is no description of the mathematical model.

The paper [2] presents the regional gravimetric survey of the central part of the Republic of Slovenia. The need for a new gravimetric survey, the survey plan and the actual field measurements are presented. Data processing, control calculations, data adjustment in the form of a gravimetric network and accuracy estimations of the results obtained during the regional gravimetric survey are described.

Today new information-measuring gravimetric systems, methods and tools of gravimetric measurements are being developed by the Ukrainian scientists of National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Zhytomyr Polytechnic State University [3].

But there is no information in the literature regarding the mathematical model of BLG that is required for further computer modeling. In this regard, the analysis of the device, the study of the main errors affecting the measurement is an urgent task.

The task of measuring gravity by ballistic methods is to measure length and time. This follows, for example, from the analysis of the dimension of acceleration. Therefore, the mathematical model should reveal the analytical relation of the path traveled by the test body with time and external influences. The most constructive approach would be to build a model in which, on the one hand, the free motion of the test body in the inertial coordinate system is considered, taking into account the vertical gradient of the gravity acceleration and the forces of resistance, and on the other, the law of motion of some coupled coordinate system is shifted under the influence of external inertial influences and holds the reference system of the gravimeter.

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Considering all researches, it can be concluded that the current scientific and technical problem today is to improve the accuracy of measurement of the gravity acceleration.

The purpose is to get a mathematical model of the new BLG and improve the measurement accuracy of the gravity acceleration.

2 Suggestions and solutions

Consideration of the free motion of a test body tilted vertically upwards in an inertial coordinate system is reduced to solving a nonlinear 2nd order differential equation of the following form:

$$m \cdot \ddot{z} = m \cdot (g_0 + \alpha \cdot z) - \gamma_1 \cdot \dot{z} - \gamma_2 \cdot (\dot{z})^2, \qquad (1)$$

where m is the mass of the test body; z is the vertical coordinate; α is the vertical gradient; γ_1, γ_2 are the coefficients that determine the contribution of resistance forces proportional to the first and second degrees of speed of motion of the test body.

Solving equation (1) by successive approximation using the Laplace transform and then decomposing it by z, leads to the following equation:

$$z(t) = g_0 \cdot \sum_{n=0}^{\infty} A_n \cdot t^n, \qquad (2)$$

where A_n is the set of coefficients (n = 0, 1, 2, ...) determined from the conditions of motion of the test body in the ballistic block relative to the reference system.

This expression describes the motion of the test body in the inertial coordinate system. The coordinates of a test body in real-world measurements of the gravity acceleration is determined by the fixed coordinate system that exposed perturbation an inertial system are uniquely dependent on its coordinates in the connected system:

$$\bar{R}_i = \bar{r} + \bar{R}, \qquad (3)$$

where $\bar{R}_i$ – a radius vector of the test body in the inertial system;

$\bar{r}$ – a radius vector of the test body in the connected system;

$\bar{R}$ – a radius vector that describes the offset of a connected system.

Generally, the ballistic gravity meter is operated so that the sensitivity axis (in our case the z axis) is held vertically. Therefore, equation (3) can be simplified:

$$S(t) = z(t) + R_z(t) \qquad (4)$$

In this expression, the component $S(t)$ describes the behavior of the test body in the inertial system, and component $R_z(t)$ – the influence of external perturbations.

Algorithms for measurements of the gravity acceleration using the described model are very diverse, both by the method of realization of free movement of the test mass and by methods of measuring the path and time.

Depending on the method of realization of the free movement of the test body, all terrestrial methods of determining g can be divided into two groups
- with asymmetrical free movement;
- with symmetrical free movement.

Using symmetric methods (both branches of the parabola in Fig. 1), the test body is tilted up, and the path and time measurements are made on the left and right branches of the trajectory.

When using asymmetric methods (right branch of the parabola in Fig. 1), the test body moves freely (falls) in the vacuum.

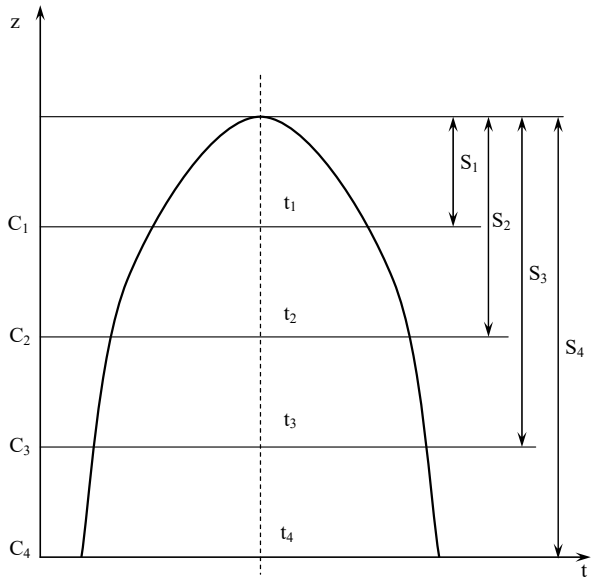

Fig. 1. The flight path of the test body in ballistic gravimeter: C_1 – C_4 – observation levels; t_1 – t_4 – moments of end of measurement intervals; S_1 – S_4 – measurement intervals.

These methods are distinguished by the relatively simple implementation of free movement and the absence of the need to apply impulse (shock) force when starting the test body, which depends on the height of the throw, which greatly improves the dynamic conditions of gravimeter [4, 5].

The advantages of symmetric methods include the possibility of virtually complete elimination of systematic errors (which is proportional to the first degree of speed of motion of the test body) with a relatively simple measurement algorithm, as well as the possibility of reducing the vertical dimensions of the device, because at the same height of the gravimeter is the total path traveled by the body in this case it will be big. However, at the moment of throw there is a pulse reactive force, which introduces an error in the measurement results.

Now we will present the set and structure, calculate and evaluate the main errors of BLG.

A further increase in accuracy is hampered by a number of circumstances, both of a fundamental (physical) and technological (economic) nature. Therefore, there is the question of optimal accuracy, which depends on many factors and is determined by limitations. These limitations need to be known so that, on the one hand, you can use all of the precise possibilities presented by the theory, and on

the other hand, do not make unsuccessful attempts to increase accuracy beyond what is possible.

Let us analyze how practical considerations shape the conditions for the required accuracy of measurements in gravimetry.

Let us take a slow (quasi-static) process. It is necessary with the given reliability β to obtain their value $\Delta x(t)$ (Fig. 2), measuring the process $x(t)$ over time τ.

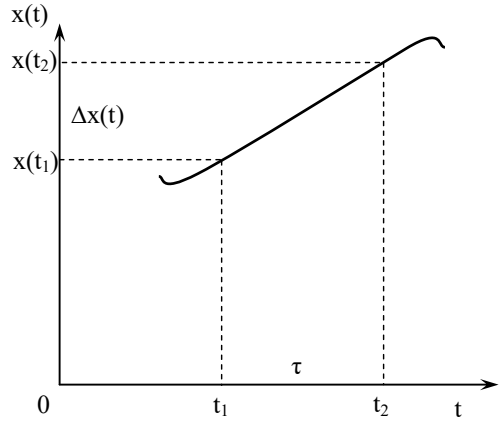

Fig. 2. The dependence of the permissible error on the drift velocity of the measurement process: $S(t)$ – change of learning parameter of process during observation τ.

The magnitude measured by $\Delta x(t)$ and the error $\delta(t)$ of BLG are related by the relation:

$$\Delta x(t) \geq \beta \cdot \delta(t), \tag{5}$$

where $\beta \geq 1$ is the number that characterizes the reliability of the measurement.

Then the Lagrange theorem on the mean in the interval under consideration can be written as follows:

$$\frac{x(t_2)-x(t_1)}{t_2-t_1} = \frac{\Delta x(t)}{\tau} = \frac{dx}{dt} = V(t),$$

whence, taking into account equation (5), we obtain:

$$\delta(t) \leq \tau \cdot \frac{V(t)}{\beta} \tag{6}$$

From equation (6) it follows that in the case of measurements of slowly changing processes, in addition to trivial to the accuracy of the measuring instrument, the requirements are also not completely obvious (measurement triviality is contained in the fact that the error of the device $\delta(t)$ must be smaller the more reliable the result is):

1) the error value of the instrument must change over time if the process speed $V(t)$ is variable;

2) the value of the error of the instrument must be less than the smaller time interval τ spent to detect changes ΔS.

Based on equation (6), we determine the maximum permissible value of $\delta(t)$.

If $\tau = 0{,}1$; $\beta = 1$; $V = 1$ μGal then $\delta = \frac{0{,}1 \cdot 1}{1} = 0{,}1$ μGal or in relative terms $\delta/g_0 = 1 \cdot 10^{-10}$.

Such an error in the measurement of the gravity acceleration is currently needed to solve some geological problems [6]. Approximately the same accuracy order is required by an exemplary gravimeter for calibration of accelerometers.

But this accuracy, at this point in time, is close to the limits recognized by some instrumental and fundamental limitations.

As is known, the error of the laser interferometer, which is a device for reproducing a unit of length, has a significant effect on the error of the gravimeter. Let us define one of the errors of the interferometer - the diffraction error caused by the limited aperture of the light beam:

$$\frac{\Delta g}{g} \approx 0{,}1 \cdot \left(\frac{\lambda}{d}\right)^2.$$

At wave length λ=0,633 μm; beam diameter d≈2 mm:

$$\frac{\Delta g}{g} = 0{,}1 \cdot \left(0{,}633 \cdot \frac{10^{-6}}{2} \cdot 10^{-3}\right)^2 \approx 1{,}0017225 \cdot 10^{-8}.$$

In modern gravimetry, the total interaction of gravitational obstacles, with the exception of the influence of the sun and the moon, is considered so small in comparison with the equilibrium of inertial forces that it can be neglected [7]. The very exclusion of the influence of inertial forces on the results of measuring the gravimeter is, at this point in time, one of the main difficulties in improving the accuracy of the determination of the gravity acceleration.

When performing gravimetric measurements of higher accuracy, a number of systematic errors are taken into account by making appropriate corrections, such as light pressure corrections, first and second order vertical and horizontal gradients, vacuum resistance, etc.

Although accurate accounting for these errors and corrections is now more difficult than measuring acceleration itself, it is fundamentally feasible. However, there are fundamental limitations that cannot be eliminated by any tools or technological means. These include the approximation of the set value of the speed of light, quantum-mechanical constraints, the limits of the accuracy of determining the acceleration gradients, fluctuations, etc.

Limitations that impose quantum mechanical laws:

$$(\Delta\bar{E})^2 \cdot (\Delta\bar{t})^2 \geq h^2 \tag{7}$$

This inequality imposes a restriction on the measurement of energy (velocity) of the body if it is to be measured at a precise time. As noted above, the acceleration g can be determined from the relation:

$$g = \frac{V - V_0}{t - t_0}.$$

Find the variance of the gravity acceleration:

$$D = M_2\{g\} = \frac{g^2}{(t-t_0)^2} \cdot [(\Delta\bar{t})^2 + (\Delta\bar{t}_0)^2] + \\ + \frac{1}{(t-t_0)^2} \cdot [(\Delta\bar{V})^2 + (\Delta\bar{V}_0)^2], \tag{8}$$

where $(\Delta\bar{t})^2$ and $(\Delta\bar{t}_0)^2$ – the variance (uncertainty) of the end and start points of time; $(\Delta\bar{V})^2$ and $(\Delta\bar{V}_0)^2$ – dispersions of the finite and initial velocities of the free-fall body.

Rewrite equation (8) using equation (7):

$$D = \frac{g^2}{(t-t_0)^2}\cdot[(\Delta\bar{t})^2 + (\Delta\bar{t}_0)^2] + \\ + \frac{h^2}{m^2(t-t_0)^2}\cdot\left[\frac{1}{V^2(\Delta\bar{t})^2} + \frac{1}{V_0^2(\Delta\bar{t}_0)^2}\right], \quad (9)$$

Investigating equation (9) for the extremum, let us determine $(\Delta\bar{t})^2$ and $(\Delta\bar{t}_0)^2$, that correspond to the minimum *D*

$$(\Delta\bar{t})^2 = \frac{h}{mVg} \text{ and } (\Delta\bar{t}_0)^2 = \frac{h}{mV_0g}.$$

So, we see that measuring of the gravity acceleration more accurately than 10^{-9} is impossible in principle due to quantum mechanical constraints, as well as fluctuations in length and time measures.

After further analysis of the literature, it can be seen that the error caused by the linear drift of the scale factor of the BLG is $\Delta_l = 0.002"$.

The error value is insignificant, so it is possible to neglect such a linear drift of the scale factor.

The error from the portable (relatively BLG) angular velocity of the Earth rotation is determined by the formula:

$$\Delta_E = \frac{\omega_z}{k},$$

where *k* is the transmission coefficient of BLG, ω_z. is the vertical component of the portable angular velocity of the Earth rotation.

Note that the vertical component of the portable angular velocity of the Earth rotation is:

$$\omega_z = \omega_E \sin\phi$$

Find the numerical value $\triangle_E$ for such parameters $k = 5\cdot10^{-3}$ kg · m, $\omega_E = 7{,}29\cdot10^{-5}$ s^{-1}.

The maximum value of the term $\frac{\omega_E \sin\phi}{k}$ corresponding to φ = 90 ° is 1,46·10^{-8} rad. That is, the error value $\triangle_E$ is small and can also be neglected.

The possibility of increasing the accuracy and speed of a ballistic gravimeter by determining the influence of the deviation of the gravity axis of the gravimeter from the local vertical direction by using digital video has been investigated [8].

The problem is solved by the fact that in the already existing gravimetric system with high-precision alignment of the axis of gravity of the gravimeter is additionally introduced video camera 5, the processor of linear approximation of the label 6, the reflecting element 7, the photoelectric autocollimator 8, and the body of the gravimeter 1 is plotted , the direction of which coincides with the direction of the axis of gravity of the gravimeter 1, and the label is optically connected to the input of the camcorder 5, the output of which is connected to the input of the processor 6 linear approximation of the label, the output of which is connected to the first input of the digital computer 3, the second input of which is connected to the output of the photoelectric autocollimator 8, the input of which is optically connected to the reflecting element 7, which is attached to the housing gravimeter 1 (Fig. 3).

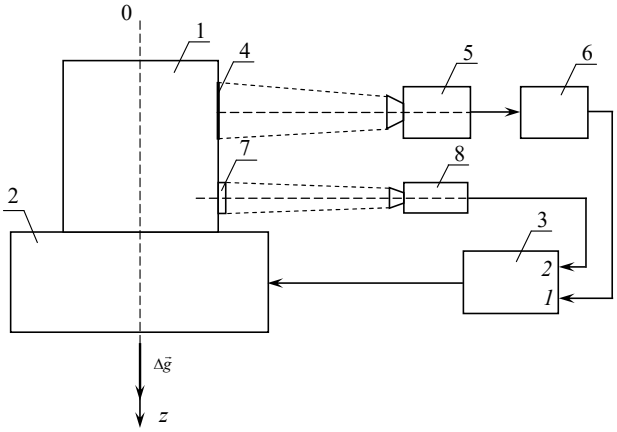

Fig. 3. Schematic diagram of a gravimetric system with high precision alignment of the axis of sensitivity of the gravimeter.

High-precision alignment of the axis of sensitivity of the gravimeter in three-dimensional space is ensured by the high-precision exposure in the three-dimensional space of the position of the plane corresponding to the surface of the reflecting element. Moreover, the mark and the reflecting element are fixed on the body of the gravimeter so that the direction of the mark coincides with the direction of the axis of sensitivity of the gravimeter, and the surface plane of the reflecting element was parallel to that axis of sensitivity [9].

The photoelectric autocollimator and camcorder are also pre-oriented in three-dimensional space so that their optical axes are perpendicular to the local vertical direction. With the help of a photoelectric auto-collimator, the deviation of the surface plane of the reflecting element from the position when it is perpendicular to the optical axis of the auto-collimator is estimated. A signal proportional to the degree of this mismatch is fed to the computer. The computer manages the spatial position of the platform in such a way so to eliminate this mismatch.

The result is an arrangement of the axis of sensitivity of the gravimeter in a vertical plane that is perpendicular to the optical axis of the photoelectric autocollimator and in which the direction of the local vertical is located.

However, the gravity axis of the gravimeter may be located in the specified vertical plane, but deviate some angle from the direction of the local vertical. This deviation can be determined by the tag, camcorder, and linear tag approximation processor. With the help of a digital computer that manages the spatial position of the platform, this deviation can be eliminated.

The result is a highly accurate alignment of the gravity axis of the gravimeter in three-dimensional space and, accordingly, its high-precision coincidence with the direction of the local vertical and the full vector of gravity acceleration.

Thus, in the gravimetric system, the accuracy of measuring the acceleration of the force of gravity is significantly increased.

3 Simulations

The problem of investigating the influence of disturbance action parameters and some own BLG parameters on the work with the help of a computer is solved.

We use the equation of motion BLG, writing it in the form:

$$\ddot{\alpha} + \dot{\alpha}[2n - L\,sin(\omega t + \varepsilon)] + \omega_0^2\alpha = \\ = N\,sin\,\omega\,t, \quad (10)$$

where $L = \frac{c_1'}{H^2}mlw_b$, $N = \frac{mlk_1}{H^2}w_a$ – vibration parameters.

Given $M(t) = 2n - L\,sin(\omega t + \varepsilon), D(t) = \omega_0^2$, then

$$\ddot{\alpha} + \dot{\alpha} \cdot M(t) + D(t) \cdot \alpha = 0, \quad (11)$$

where $M(t)$ and $D(t)$ are T-periodic functions, $\dot{M}(t)$ and $\dot{D}(t)$ assume integrated piecewise-continuous.

The equation of the form (11) can be reduced to a similar one without changing the characteristic indices, where $M(t) = const$.

$$\int_0^t M(t_1)dt_1 = \aleph t + M_1(t),$$

where

$$\aleph = 2n;\ M(t_1) = \int_0^t [M(t_1) - \aleph]\,dt = \frac{L}{\omega}cos(\omega t + \varepsilon),$$

and $M_1(t)$ is T-periodic function.

Replacing

$$\alpha = e^{-\frac{1}{2}M_1(t)}x = e^{-\frac{1}{2}\frac{L}{\omega}cos(\omega t+\varepsilon)}x, \quad (12)$$

we get

$$\ddot{x} + 2n\dot{x} + F(t)x = 0, \quad (13)$$

where

$$F(t) = D(t) - \frac{1}{4}M^2(t) - \frac{1}{2}\dot{M}(t) + \frac{1}{4}\aleph^2 = \\ = \omega_0^2 + \nu_0\,sin(\omega t + \varepsilon + \sigma_8), \quad (14)$$

where $\sigma_8 = arctg\frac{\omega}{2n}$, $\nu_0 = \frac{L\sqrt{\omega\ +4n^2}}{2}$.

Given (5.1) and (5.5), expression (5.4) can be written as

$$\ddot{x} + 2n\dot{x} + [\omega_0^2 + \nu_0\,sin(\omega t + \varepsilon + \sigma_8)]x = N\,sin\,\omega\,t \quad (15)$$

or, taking into account the real BLG parameters:

$$\ddot{x} + 2\xi\omega_0\dot{x} + (\omega_0^2 + \nu_1 w_b\,sin\,\omega\,t)x = 0{,}625w_a\,sin\,\omega\,t, \quad (16)$$

where $\nu_1 = \frac{\nu_0}{w_b}$.

Therefore, the BLG motion equation (10) is transformed into one equation (16), which is convenient for computer simulation. The equation obtained is a Mathieu-Hill equation [10-12].

The graphs of some functional dependences for certain values $w_a, w_b\,\omega$, as well as the values of the damping coefficient ξ, are shown in Fig. 4, 5, 6.

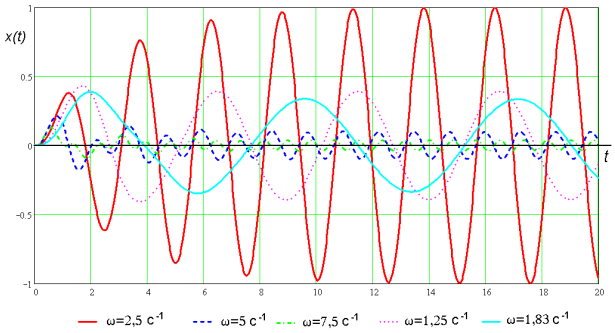

Fig. 4. Graphs of change of output signal for different values ω.

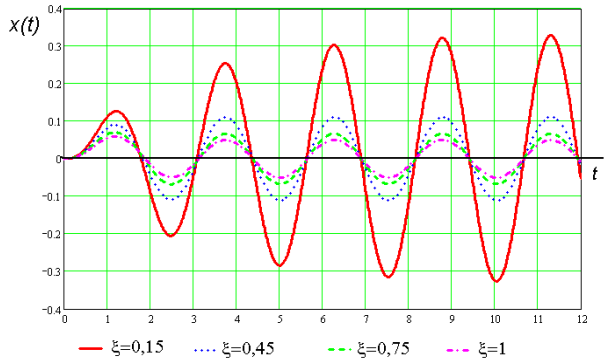

Fig. 5. Graphs of change of the output signal $x(t)$ for different values of the damping factor ξ.

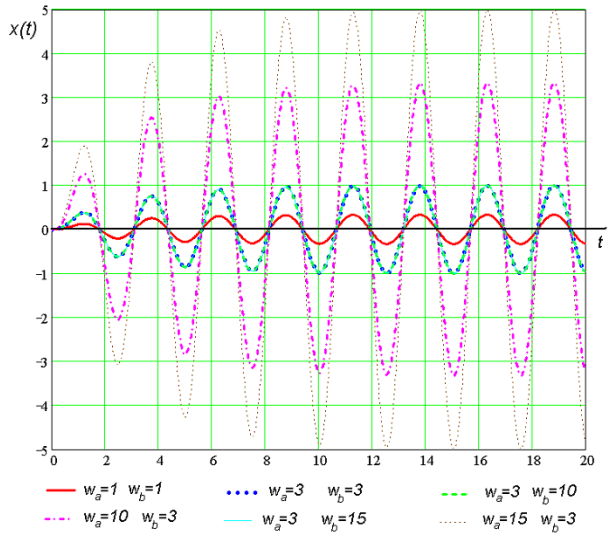

Fig. 6. Graphs of output signal $x(t)$ changes for different values w_a, w_b.

The graphs show that:

– at perturbation frequency $\omega = \omega_0 = 2{,}5$ s^{-1} the main resonance occurs, the most dangerous for the BLG;

– at perturbation frequency $\omega = \omega_0/2 = 1{,}25$ s^{-1}, $\omega = \omega_0/3 = 0{,}83$ s^{-1} the output signal is not distorted (sub harmonic oscillations are set);

– at perturbation frequencies $\omega = 2\omega_0 = 5$ s^{-1}, $\omega = 3\omega_0 = 7{,}5$ s^{-1} the output signal is distorted (beating is set);

– increasing the amplitudes of horizontal accelerations does not affect the amplitude of the forced oscillations of the BLG $x(t)$;

– the amplitudes of the forced oscillations along the axis of the BLG sensitivity are directly proportional to the amplitudes of the perturbing vibration accelerations along the axis of the BLG sensitivity.

In order to compare the above information, the results of modeling the equations of motion of BG on the computer are summarized in Table 1.

Table 1. The amplitudes of the steady forced oscillations of the BLG.

ω, s^{-1}	α, rad
0,83	$0{,}22 \cdot 10^{-7}$
1,25	$0{,}65 \cdot 10^{-7}$
2,5	$1{,}86 \cdot 10^{-6}$
5,0	$0{,}93 \cdot 10^{-6}$
7,5	$4{,}7 \cdot 10^{-7}$

Comparing the amplitudes of the steady forced oscillations of the BLG at $\omega = \omega_0$, $3\omega = \omega_0$, $2\omega = \omega_0$, $\omega = 2\omega_0$, $\omega = 3\omega_0$; $\xi = 1$; $w_a = w_b = 1$ m/s^2, calculated in accordance with expression (12) (Table 1), it is seen that the amplitudes of the steady forced oscillations of the BLG are greatest, provided that the frequency of the natural oscillations of the BLG and the disturbing influence are equal.

Digital simulation of the effect of perturbation parameters on the BLG, as well as the eigen parameters, confirmed the main advantage of the BLG over the known gravimeters – its higher accuracy (mean square error of 0,1 μGal).

4 Conclusions

A refined mathematical model of the new BLG was obtained. The composition and structure of the main errors of the BLG are given. The main errors of the BLG are calculated and estimated. The computer simulation of BLG behavior for the most unfavorable resonance modes for different ratios of disturbing factors and intrinsic BLG parameters is performed. The conclusions made in the analytical study of the work of BLG are confirmed: the most dangerous from the point of view of resonance occurrence is only the case of coincidence of perturbation frequency with the frequency of natural BLG oscillations. As the damping factor increases, the resonance disappears. The main advantage of BLG over the known gravimeters was confirmed – its greater accuracy (mean square error of 0.1 μGal). It is proposed to use digital video in the new BLG as a carrier of measurement information. This extends the functionality and also significantly improves the accuracy of measurements of the gravity acceleration. This reflects the modern engineering and technological solutions of the information technology era in the sustainable development of society.

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Research of algorithms of Data Mining

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Abstract. The article explores data mining algorithms, which based on rules and calculations, that allow us to create a model that analyzes the data provided by searching for specific patterns and trends. The purpose of this work is to analyze correlation-regression algorithms on a statistical dataset of chronic diseases. Data mining allows building many models, multiple algorithms can be used within a single solution. The article explores the algorithms of clustering, correlation analysis, Naive Bayes algorithm for obtaining different views of data. Since diabetes is one of the most dangerous chronic diseases, the pathogenesis of which is a lack of insulin in the human body, which causes metabolic disorders and pathological changes in various organs and tissues. As a result, it leads to disability of all functional systems of the body. It was decided to investigate the data related to this disease. Also, the quality of the developed methods of information retrieval from the dataset was evaluated and the most informative features were identified. The developed methods were implemented in the system of intellectual data processing. Past studies show promise of using data mining methods to improve the quality of patient care.

1 Introduction

The health care system is fully controlled by the state. According to the determined vectors and strategic vision of the Sustainable Development Strategy of Ukraine until 2030, one of the focuses is on providing an effective public health system, providing effective medical services, which is impossible without the use of modern information technologies [1]. The use of modern information technology is impossible without green IT [2].

The complexity of the experiments in this area is due to the object of the study, that is, human health. Most experiments on human health have legislative restrictions, as this can cause damage and prevent human rights. Therefore, the use of methods of data mining, in this case, for the analysis of already collected data can allow revealing a lot of hidden information, based on which further decisions can be made.

There are many algorithms for data mining. The purpose of this is to find patterns in the data. The knowledge gained through the methods of Data mining is accepted to be represented in the form of regularities (patterns) [3]. The article deals with classification algorithms and correlation-regression algorithms.

1.1 Analysis of published data

Volozhanin defines the basic concepts of correlation and calculates the correlation coefficient between the digital (numeric) value of each factor and the result of the sports. But the author does not use mathematical tools for analysis and does not provide specific research results [4]. The article [5] by the author team researched the detection of pathogenetic correlations between the parameters of standard laboratory methods of research in patients with iron deficiency anemia with chronic blood loss. Using the language R, a statistical analysis of the laboratory parameters was performed and the inherent correlations were established. Differences were found in correlation relationships between indicators, which reflect profound pathogenetic changes, using differentiation. These results have practical value for the assessment of the severity of metabolic damage and to monitor treatment effectiveness.

The systematic approach to the training of athletes is considered in the article [6]. Usage patterns of mathematical statistics methods in sports analysis are considered. Out of several methods, more reliable ones for detecting correlation relationships were chosen. The article uses a Fechner coefficient to determine the closeness of links between objects.

The article [7] presents an approach to the recognition of localized road signs using the method of support vector machine and histograms of oriented gradients. A method of plotting histograms of oriented gradients that do not depend on image size is proposed. For problems with multiple classes, the method of support vector machine is generalized. The experimental data show the advantages of the proposed method. The disadvantage of this study is that the experiment is not sufficiently covered.

The article of Andreeva [8] investigates the correlation analysis of the results of sociological researches to the

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problem of attitude of the city population to the number of days off needed to celebrate the new year was explored. Statistical relationships were found between different feature groups. This study does not describe the algorithms that were used in the work.

1.2 Formulation of the problem

The purpose of the study is to use the algorithms of data mining for the processing of statistics and research into green IT creation and implementation processes:
- researching correlation-regression algorithms;
- the use of the support vector method;
- conducting research (exploratory) analysis;
- selection of the most unexpected dependencies.

2 Description of the data source

Unfortunately, medical statistics in Ukraine are not yet able to provide the necessary amount of statistical information for analysis and boast the extensive use of green IT. Therefore, the US Centers for Disease Control and Prevention (CDC) may be one of the sources for research. Chronic Disease Statistics in 500 U.S. cities were selected for data analysis based on information collected by the CDC [9]. This data is unique in itself because it covers 103 million people aged 18 and older and has 27,210,000 records across different statistical reporting territories, with populations ranging from 50 to 26,980. Also included in the data is the state, district, city, geographic coordinates, which further expands the analysis based on other statistics, for example, average household income, unemployment rate and more.

The indicators are divided into three main groups:

1. Unhealthy lifestyle (5 indicators).
2. Chronic diseases (13 indicators).
3. Population coverage by preventive methods (9 indicators).

All metrics are presented as a percentage of the population and a range of errors. The CDC, as a government organization, has sufficient resources to ensure that statistical information is collected and further processed. Chronic illness statistics are already a normalized database and contain information from verified sources.

Naive Bayes classifier belongs to a family (type) of probabilistic classifiers using the Bayes' theory. Despite its simplicity, the Naive Bayes classifier remains one of the most popular methods of solving the problem of text categorization, the problem of identifying documents that fall into one category or another. The purpose of the naive Bayesian classifier is to calculate the conditional probability by the formula (1):

$$p(C_k|x_1, x_2, \dots, x_n) \quad (1)$$

For each of k the possible outcomes or classes C_k.

Let (may, if) $x = (x_1, x_2, \dots, x_n)$. Using Bayes' theorem, we can obtain, get the formula of the form (2):

$$p(C_k|x) = \frac{p(C_k)p(x|C_k)}{p(x)} \propto p(C_k)p(x|C_k) = \\ = p(C_k, x_1, x_2, \dots, x_n) \quad (2)$$

The joint probability can be written as (3):

$$p(C_k|x_1, x_2, \dots, x_n) = \\ = p(x_1|x_2, \dots, x_n, C_k) \cdot p(x_2, \dots, x_n, C_k) = \\ = p(x_1|x_2, \dots, x_n, C_k) \cdot p(x_2|x_3, \dots, x_n, C_k) \cdot \\ \cdot p(x_3, \dots, x_n, C_k) = p(x_1|x_2, \dots, x_n, C_k) \cdot \\ \cdot p(x_2|x_3, \dots, x_n, C_k) \cdot p(x_n|C_k) \cdot C_k \quad (3)$$

Assume that all functions x mutually independent, we can get the formula (4):

$$p(x_1|x_2, \dots, x_n, C_k) = p(x_1|C_k) \quad (4)$$

Therefore, the formula can be written as (5). So, it is the final formula for naive Bayesian classifiers. We offer training and testing in Python programming language.

$$p(C_k|x_1, x_2, \dots, x_n) \propto p(C_k, x_1, x_2, \dots, x_n) = \\ = p(x_1|C_k) \cdot p(x_2|C_k) \dots \cdot p(x_n|C_k) \cdot p(C_k) = \\ = p(C_k) \prod_{i=1}^{n} p(x_i|C_k) \quad (5)$$

The training model is represented in the Python programming language is:

```
def train_dataset_for_column(column_to_predict):
  column_to_predict = column_to_predict
  train, test = train_test_split
    (data_only_crude_prev, test_size=0.2)
  best_chooser = BestSelectionTrainAlgorithm(
    lambda: linear_model.LinearRegression())
  best_chooser.max_best_indicators_count = 5
  best_chooser.low_score_for_best = 0.7
  best_chooser.max_combine = 2
  best_chooser.y_column_preparer =
    lambda data_frame: data_frame.astype(int)
  best_indicators =
best_chooser.best_indicators_from(train, test,
column_to_predict)
  descr = 'Best indicator for ' +
    column_to_predict + '\n'
  for train_result in best_indicators:
   train_result.columns_by_predict,accuracy=2.0)
    descr = descr + '
'.join(train_result.columns_by_predict) + ' ' +
column_to_predict + ': ' +
str(train_result.score) + '\n'
str(train_result.model.intercept_) + '\n'
  descr = descr + "\n\n"
  print(descr)
```

The testing model is represented in the Python programming language is:

```
def test_prediction_accuracy(model, test,
column_to_predict, column_by_predict,
accuracy=0.0):
  count_of_test_rows = len(test)
  count_of_close_predicted = 0
  test_by = test[column_by_predict].values
  test_to = test[column_to_predict].values
  predicted_values = model.predict(test_by)
  for i in range(0, count_of_test_rows):
    if isclose(predicted_values[i], test_to[i],
      abs_tol=accuracy/2):
      count_of_close_predicted += 1
  return count_of_close_predicted/
```

```
    count_of_test_rows
if __name__ == '__main__':
  mp.freeze_support()
  columns = data_only_crude_prev.columns.values
  p = mp.Pool(3)
  results = p.map(train_dataset_for_column,
columns)
```

Support vector machine provides significant accuracy with less computing power and can be used for both regression and classification problems. The purpose of the algorithm is to find a hyperplane in an *N*-dimensional space (*N* is the number of features) that clearly classifies data points (see Fig. 1).

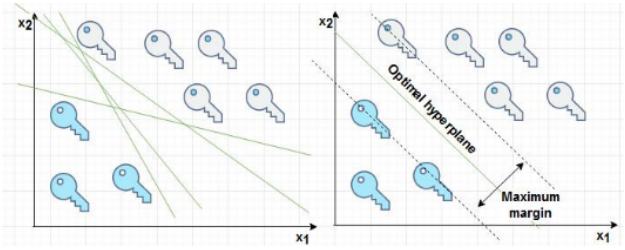

Fig. 1. Possible hyperplanes.

To separate the two classes of data points, there are many possible hyperplanes to choose from. The goal of the algorithm is to find the plane, which has a maximum margin (stock, reserve), that is, the maximum distance between data points of both classes. Maximizing the margin (stock, reserve) distance provides some reinforcement so that future data points can be classified with greater confidence.

Data points that fall on either side of the hyperplane can be classified into different classes. Also, the dimension of the hyperplane depends on the number of features (sighs, characteristics). If the number of input objects is 2, then the hyperplane is just a line. If the number of input objects is 3, then the hyperplane becomes a two-dimensional plane. It becomes difficult to imagine when the number of functions exceeds 3 [11].

The purpose of the algorithm is to maximize the difference between the data points and the hyperplane. A loss function that helps maximize margin is a hinged loss. The cost function and gradient renovation, (6):

$$c(x,y,f(x)) = \begin{cases} 0, & if.\, y * f(x) \geq 1 \\ 1 - y * f(x), & else \end{cases} \quad (6)$$

Cost is 0 if the predicted value and the actual value have the same sign. If this condition is not fulfilled – it is necessary to calculate the amount of damage. We also add a parameter of the regularization of the cost function. The task of the regularization parameter is to balance the maximization of margins and losses. After adding the regularization parameter, the cost functions are as follows, (7):

$$min_w\, \lambda\, ||w||^2 + \sum_{i=1}^{n} (1 - y_i(x_i, w))_+ \quad (7)$$

Once the loss function is known, it is possible to take private derivatives by weight to find gradients. Using gradients can be updated weight, (8), (9):

$$\frac{\delta}{\delta w_k} \lambda ||w||^2 = 2\lambda w_k \quad (8)$$

$$\frac{\delta}{\delta w_k}(1 - y_i\langle x_i, w\rangle)_+ = \begin{cases} 0, & if.\, y_i\langle x_i, w\rangle \geq 1 \\ -y_i x_{ik}, & else \end{cases} \quad (9)$$

When the model makes a mistake in the prediction of a data point class, it is necessary to include the loss along with the regularization parameter to update the gradient, (10):

$$\omega = \omega + a \cdot (y_i \cdot x_i - 2\lambda\omega) \quad (10)$$

When the model correctly predicts the data point class, all that is need to do is to update the gradient of the regularization parameter, (11):

$$\omega = \omega - a \cdot (2\lambda\omega) \quad (11)$$

The Best Selection Train Algorithm class was developed to implement the **support vector machine**.

For the selection of indicators that are significantly correlated with each other, this class has the following fields:

1. max_best_indicators_count – the maximum number of indicators to be selected.
2. low_score_for_best – a minimum estimate of the accuracy of the model (used to ensure that the model based on the model was considered the best).
3. max_combine – the number of elements in the array based on which the prediction is made (it should be noted that the long-term operation of the algorithm may be required when this indicator is of great importance).
4. y_column_preparer – the method used to prepare the test data (for example, the Bayesian algorithm cannot predict non-discrete values (such as float), so in this method, the Float value can be converted to Int).

The training model implements the following methods:

1. def fit(self, X, y) – a method for training the model, where **X** – an array of values that the training is based on, *y* is the expected value.
2. def score(self, X, y, sample_weight=None) – a method for estimating the quality of model prediction, where **X** – an array of values on which testing takes place, *y* is the expected value.

The model is built using the support-vector machine and depends only on the subset of the training data and in some cases gives the best result of regression analysis.

Exploratory data analysis. To investigate the relationship between the data, we use the Pearson correlation coefficient (Table 1), the values of which are interpreted based on absolute values. Possible values vary from 0 to ± 1. To evaluate the bond strength, a Cheddock table is usually used, according to which, absolute values less than 0.3 indicate weak bond strength, 0.3 to 0.5 – moderate, 0.5 to 0.7 - significant, 0, 7 – 0.9 - high, a value greater than 0.9 – very high. Figure 2 presents the matrix of correlation indicators (heat map) obtained by using linear regression and estimation of the results of the coefficient of determination (R-square).

After analyzing the indicators, some patterns have been identified that are logical. For example, a visit to a dentist leads to tooth loss. The lack of health insurance for

adults 18-64 years old (ACCESS2_CrudePrev) correlates with the prevalence of visits to a dentist or dental clinic for adults 18 years of age (DENTAL_CrudePrev). A correlation was found between such indicators as the prevalence of arthritis in adults 18 years of age (ARTHRITIS_CrudePrev) and high blood pressure in adults 18 years of age (BPHIGH_CrudePrev), a correlation coefficient of 0.75.

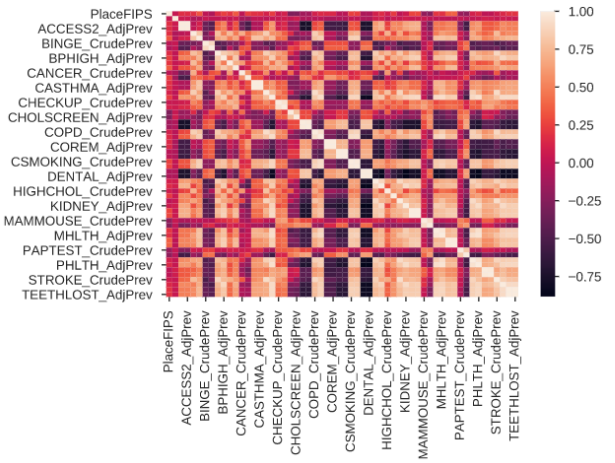

Fig. 2. Matrix of correlation indicators.

Correlations were also found between such indicators as the prevalence of arthritis among adults aged 18 and over (ARTHRITIS_CrudePrev) and chronic obstructive pulmonary disease in adults 18 years and older (COPD_CrudePrev) – correlation coefficient of 0,65.

Special attention has been paid to the correlation of diagnosed diabetes mellitus in adults aged 18 years (DIABETES) with other diseases. Diabetes mellitus is a disease that is included in the group of "leaders" along with cardiovascular and oncological diseases and is called the "disease of the century". If it was previously thought that diabetes is a disease of the elderly, then in the 21st century, it "became younger" and every year becomes "younger" and grows with a geometric progression.

This disease is in third place after cancer and cardiovascular. People are increasingly ill, even though medicine is improving day by day. The growing trend of cardiovascular, cancer, mental illness, and diabetes is observed not only in our country but also in more developed countries such as America. Table 1 presents some correlation indicators for the selected study object – DIABETES.

In the early stages of project development, it is often necessary to perform Exploratory data analysis (EDA) in order to identify patterns that identify the data. Data visualization helps to present large and complex datasets in a simple and visual way. Figure 3-4 shows the patterns between DIABETES_CrudePrev and other features.

The distribution density of two variables gives a gradient (Fig. 5), which in its direction indicates the direction of the greatest growth of a quantity whose value varies from one point of space to another and in magnitude is equal to the rate of growth of this value in this direction. The graphs presented in Figure 5 confirm the results of the studies. You can make sure that density of distribution of indicators DIABETES_CrudePrev and BPHIGH_CrudePrev, STROKE_CrudePrev, LPA_CrudePrev are better than DIABETES_CrudePrev and CASTHMA_CrudePrev.

Table 1. Correlation coefficients.

	DIABETES_CrudePrev
ACCESS2_CrudePrev	0.614854
BPHIGH_CrudePrev	0.846432
BPMED_AdjPrev	0.560538
CASTHMA_CrudePrev	0.357883
ARTHRITIS_AdjPrev	0.478496
BPMED_CrudePrev	0.572423
CANCER_CrudePrev	0.052244
CHD_CrudePrev	0.780102
CHECKUP_CrudePrev	0.514177
CHOLSCREEN_CrudePrev	0.100295
COLON_SCREEN_CrudePrev	-0.640006
COPD_CrudePrev	0.696707
CSMOKING_CrudePrev	0.639347
KIDNEY_CrudePrev	0.900171
LPA_CrudePrev	0.832808
OBESITY_CrudePrev	0.729541
SLEEP_CrudePrev	0.716363
STROKE_CrudePrev	0.862107
TEETHLOST_CrudePrev	0.751177

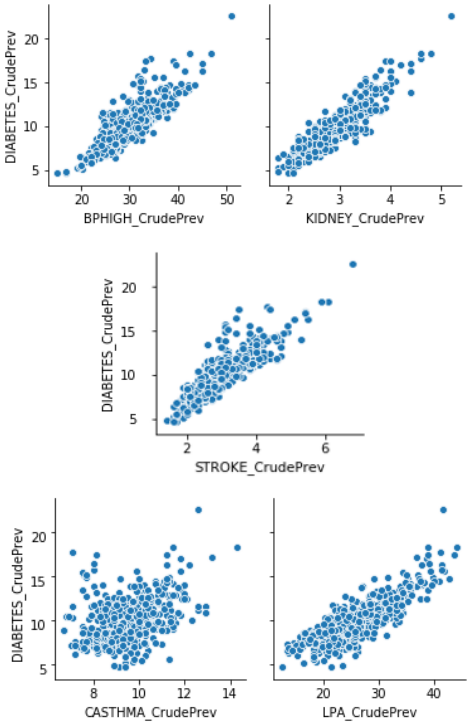

Fig. 3. Dependence between diabetes and other diseases.

To solve the problem of machine learning, the Scikit library was used. This library provides a wide variety of algorithms for (un)supervised learning.

The developed method [12] receives some elements on input, such as model, test data, name of the column for prediction, the names of the columns based on which the prediction is made, the desired accuracy of prediction (as absolute values), the way the test data is prepared.

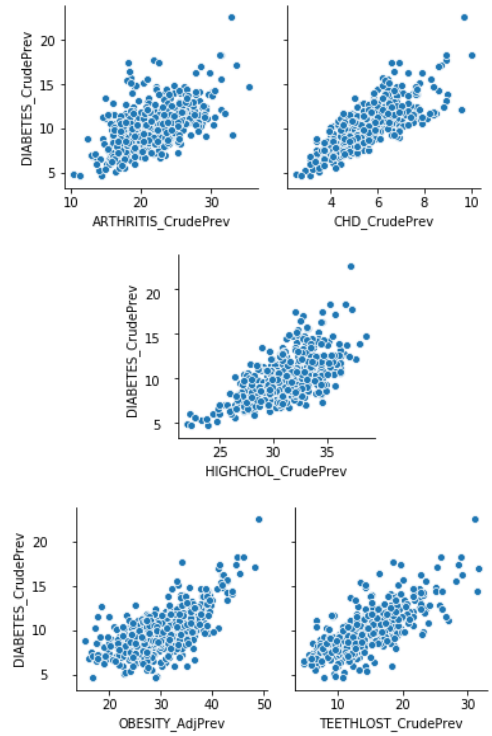

Fig. 4. Dependence between diabetes and other diseases.

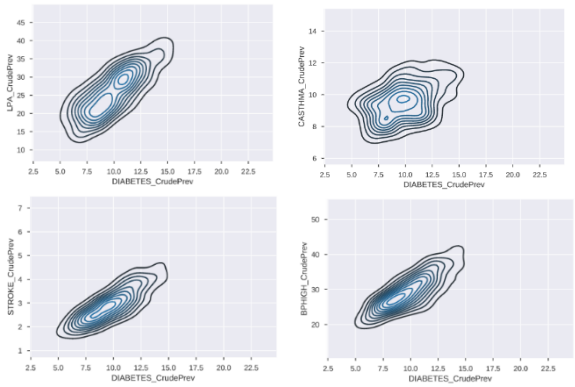

Fig. 5. Density distribution by parameters.

Also, the method of least squares for testing was used, which is defined as $1-\frac{u}{v}$, where u is the sum of squared errors of prediction:

$$\sum_{i=0}^{n}(y_{i\ \ actual}-\ y_{i\ \ predict})^2, \qquad (12)$$

and v is the total sum of squares of the difference between the mean of the dependent variable and the exact value:

$$\sum_{i=0}^{n}(y_{i}\ \ -\ y_{i\ \ average})^2 \qquad (13)$$

As a result, a versatile method for estimating the quality of predicting was developed, that can be used to create green IT. Additionally, a deviation of ± 1%. As a result of the research, it is determined that various methods of data mining predict the prevalence of chronic diseases with sufficient accuracy.

Conclusions

A correlation-regression analysis of chronic disease statistics was conducted based on the data set of the American Centers for Disease Control and Prevention (CDC). Models for Naive Bayes classifiers are developed. The support vector machine was used for classification and regression analysis.

An exploratory data analysis was performed, in which it was discovered unexpected dependencies between diagnosed diabetes mellitus among adults and high blood pressure, kidney disease, coronary artery disease and loss of all teeth.

As a result of the researches of the mentioned algorithms of data mining, models and methods were developed to establish the impact of some chronic diseases on others.

To increase the reliability of the results using the proposed models and methods, it is necessary to increase the amount of data. The studies conducted provide the basis for the practical design of energy efficient data processing centers.

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Enhancement of alkali-activated slag cement concretes crack resistance for mitigation of steel reinforcement corrosion

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Abstract. The paper is devoted to mitigation of steel reinforcement corrosion in alkali-activated slag cement (further, AASC) concretes, based on soluble sodium silicates (further, SSS's), obtained from high consistensy concrete mixes. Enhancement of AASC fine concretes crack resistance due to modification by complex shrinkage-reducing additives (further, SRA's) based on surfactants and trisodium phosphate $Na_3PO_4 \cdot 12H_2O$ (further, TSP) was proposed for mitigation of steel reinforcement corrosion. SSS's were presented by sodium metasilicate (silica modulus 1.0, dry state) and water glass (silica modulus 2.9, density 1400 kg/m^3). In case of sodium metasilicate the application of SRA composition "ordinary portland cement clinker – TSP – sodium lignosulphonate – sodium gluconate" provides enhancement of crack resistance starting from early age structure formation with restriction of drying shrinkage from 0,984 to 0,713 mm/m after 80 d. The effect is caused by reduction of water and by higher volume of crystalline hydrates. In turn, SRA presented by compositions "TSP – glycerol" and "TSP – glycerol – polyacrylamide" provide enhancement of AASC fine concretes fracture toughness during late structure formation with increasing ratio of tensile strength in bending to compressive strength up to 37 – 49 % if compare with the reference AASC when water glass is used.

1 Introduction

The actuality of green materials implementation is due to their conformity with modern tendencies of building industry development in the part of efficient consumption of raw materials and energy resources, responsible attitude to ecology of the environment, while ensuring high quality, functionality and durability of building materials. Thus eco-efficient composite cements, based on slag, zeolite, fly-ash, limestone as well as microsilica, ensure high early strength of mortars [1, 2]. Application of a highly dispersed chalk as an additive in these cements increases strength, waterproof and freeze-thaw resistance of concretes [3, 4].

Alkali-activated slag cement (further, AASC) are the most perspective environmentally friendly one in view of the modern tendencies of sustainable development. The ecological benefits of AASC's are caused by reduction of CO_2 emission while consumption of by-products as well as waste products [5, 6, 7]. AASC mortars and concretes are characterized by increased strength [8, 9], heat resistance [10, 11], corrosion resistance [12, 13], freeze-thaw resistance [14, 15] and waterproof [16] in comparison with analogues based on traditional clinker cements.

Thus, AASC's are effective for strategic construction objects with special destination (fortifications, sea ports, bridge foundations, tunnels, etc.), which must be exploited in various aggressive mediums. AASC based on soluble sodium silicates (further, SSS) is the most interesting type, first of all due to comparative strength benefits. This fact is relevant for special concretes.

High durability of AASC reinforced concretes obtained from harsh (low consistency) concrete mixes was already proved by long-term exploiting experience [17-21]. However, the modern requirements to high consistency fresh concretes are governed by practice. This way the disturbance of reinforcement passive state can be caused by changes in hardened concrete structure. The means for protection of reinforcement in such AASC concretes must be developed. One of decisions is the enhancement of crack resistance during all stages of service life cycle.

AASC concretes along with high strength are characterized by increased drying shrinkage and fracturing [22, 23, 24] due to high content of gel during initial structure formation. The drying shrinkage causes heterogeneous structure of concrete during further structure formation and as a result the unstable characteristics of artificial stone [25].

There are number of means to prevent fracturing, for example fiber reinforcement of concrete [26]. It's also well known, that surfactants allow regulating consistency while ensuring high strength of concrete. Diminution of drying shrinkage is a result of decreased water. Most of surfactants are ineffective for AASC and therefore the principles for their choice were proposed [27, 28]. The maximum water-reducing effect in this

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case can be provided by sodium lignosulfonate [29], sodium gluconate [30], polyhydric alcohols [27], etc. Triatomic alcohol glycerol and polyacrylamide are the most perspective modifiers of AASC's based on water glass. These admixtures bind surface groups of silicic acid oligomers by means of hydrogen links while ensuring high strength, waterproof and elasticity of AASC mortars and concretes [31, 32, 33].

Another mean for drying shrinkage mitigation is complex application of admixtures and additives. It was shown the effectiveness of salts-electrolytes, like Na_2SO_4 [34], and by-pass cement kiln dust, which typical components are free CaO and salts (KCl, NaCl, K_2SO_4, Na_2SO_4, $CaSO_4$, K_2CO_3, Na_2CO_3, $CaCO_3$, etc.) [35, 36]. Trisodium phosphate $Na_3PO_4{\cdot}12H_2O$ (further, TSP) is well-known retarder of AASC setting time [37, 38]. TSP also ensures effect of water glass stabilizer to prevent early coagulation while interaction with slag in AASC [39]. Moreover, TSP can be used as inhibitor of steel reinforcement corrosion due to formation of chemical stable products like hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$ [37] with formation of a dense protective film on metal surface [40, 41], increasing polarization resistance of rebar [42, 43] as well as decrease of capillary pore network with time [44].

The fundamentals of mineralogy and chemistry can give some explanations concerning effect of the mentioned compounds on the structure of AASC stone, namely about isomorphism with replacing of silicate or aluminate anion, formation of solid solutions or additional crystalline formations, which reduce the proper deformations [45]. These compounds can be used as complex modifiers of AASC.

Increasing of AASC's crack resistance in consequence of drying shrinkage mitigation can also be accomplished by increasing crystallinity of hydrated phases when using high-calcium additives such as ordinary portland cement clinker (further, OPC clinker) [18, 46] or lime [47, 48].

The above results allows to predict increasing of AASC crack resistance due to complex shrinkage-reducing additives (further, SRA's) in the system "additives – surfactants". Specified method was proposed for mitigation of steel reinforcement corrosion in high consistency AASC concretes, modified with SRA's based on salts-electrolytes, i.e. Na_2SO_4 and $NaNO_3$ [24, 49, 50]. The effectiveness of these SRA's was explained by their co-acting in crystallization processes, alteration of porous structure as well as morphology of hydrated phases.

The aim of this research was to ensure crack resistance of AASC concretes, based on SSS and plasticized by SRA's, for mitigation of steel reinforcement corrosion during all stages of structure formation.

2 Raw Materials and Methods

Five compositions of AASC based on SSS were used:
- # 1 - the reference AASC based on sodium metasilicate (ground granulated blast furnace slag (further, GBFS) – 88.20 %, sodium metasilicate – 11.80 % (3.91 % by Na_2O));
- # 2 - AASC based on sodium metasilicate, modified by SRA composition "OPC clinker – TSP – sodium lignosulphonate – sodium gluconate" (GBFS – 83.80 %; sodium metasilicate – 11.20 % (3.91 % by Na_2O) ; SRA – 5 %);
- # 3 - the reference AASC based on sodium water glass (GBFS – 71.74 %; water glass, modified by TSP – 28.26 %);
- # 4 - AASC based on sodium water glass, modified by SRA composition "TSP – glycerol" (GBFS – 71.65 %; water glass, modified by TSP – 25.65 %, glycerol – 2.70 %);
- # 5 - AASC based on sodium water glass, modified by SRA composition "TSP – glycerol – polyacrylamide" (GBFS – 71.65 %; water glass, modified by TSP – 25.65 %, glycerol – 2.69 %, polyacrylamide – 0.01 %).

GBFS, basicity modulus= 1.1, content of glass phase= 84 %, specific surface= 450 m^2/kg (by Blaine), was used as AASC aluminosilicate component.

SSS were used as AASC alkaline components:
- five-water sodium metasilicate ($Na_2SiO_3{\cdot}5H_2O$), dry state;
- sodium water glass, modulus M_s= 2.9, density= 1400 kg/m^3.

Surfactants in SRA's were presented by:
- sodium lignosulphonate (further, LST) according to CAS 8061-51-6 (pH ≥ 8.5) and sodium gluconate according to CAS 527-07-1 (for AASC's based on sodium metasilicate);
- glycerol according to CAS 56-81-5 and polyacrylamide according to CAS 9003-05-8 (for AASC based on water glass).

Additives in SRA's were presented by:
- OPC clinker (CaO – 66.15 %; SiO_2 – 22.61 %; Al_2O_3 – 5.29 %; Fe_2O_3 – 3.93 %; MgO – 0.84 %; Na_2O – 0.15 %, K_2O – 0.98 %, SO_3 – 0.50 %), specific surface= 450 m^2/kg (by Blaine);
- $Na_3PO_4{\cdot}12H_2O$ (TSP) according to CAS № 7601-54-9.

The content of TSP was accepted experimentally while providing allowable initial setting time (not less 15-20 min). TSP was dissolved in water glass to provide density= 1400 $кg/m^3$.

Normal consistency of cement pastes and setting time were determined according to the national standard of Ukraine DSTU B V.2.7-185:2009.

The standard quartz sand in accordance with EN 196-1 was used as a fine aggregate to determine strength and proper deformations of AASC concrete.

Cement pastes and fine concrete mixes were prepared in mixer Hobart type.

Water-reducing effect of SRA's was evaluated by decreasing W/C ratio in AASC/sand mixes (1:3) with slump flow= 106-115 mm on flow table according to the national standard of Ukraine DSTU B V.2.7-187:2009. The strength and proper deformations of AASC fine concrete were determined on specimens 40x40x160 mm. After manufacturing and hardening in forms with an insulated surface for 1 day, the samples were stored for 7 d under the normal conditions (t= 20 ± 2 °C, R.H. = 95 ± 5 %). Then the samples were stored over

saturated solution of potassium carbonate (NH_4NH_3) at t= 20 ± 2 °C till the control age. The length of samples after 1 d was taken as the initial one (zero) in calculations.

Analysis of elastic-deformed state of AASC concretes under load was realized by bending test while determination of deformations up to destruction of samples (Fig. 1). Fracture toughness was estimated by the values of tensile strength in bending to compressive strength ratio. This method allows to determine effect of cement composition as well as structural features of cement on the values of deformation and destruction [51].

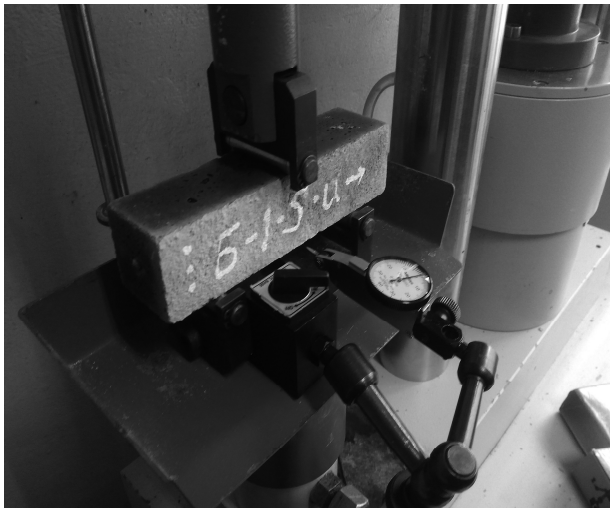

Fig. 1. Testing of samples under load.

Research of microstructure of artificial stone was carried out by differential-thermal analysis (DTA) and electronic microscope with micro analyzer.

3 Results and discussion

Effect of SRA's in the system "additives – surfactants" on crack resistance of AASC fine concrete (further, concrete) are shown on examples.

3.1 Enhancement of crack resistance of alkali-activated slag cement concrete based on sodium metasilicate

Characteristics of the reference AASC (without SRA): normal consistency of cement pastes – 21.67 %, initial setting time – 45 min, final setting time – 45 min. The tensile strength in bending / compressive strength of AASC concrete (W/C ratio = 0.29): 5.04 / 28.8 MPa (2 d), 6.1 / 40.0 MPa (7 d) and 7.5 / 50.3 MPa (28 d).

Effect of SRA composition "OPC clinker – TSP – LST – sodium gluconate" on drying shrinkage of AASC concrete was researched (Fig. 2). The reference AASC concrete is characterized by high drying shrinkage during the initial structure formation. SRA composition "OPC clinker – TSP – LST – sodium gluconate" ensures formation of AASC concrete with preferable structure and mitigation of drying shrinkage from 0,984 down to 0,713 mm/m after 80 d.

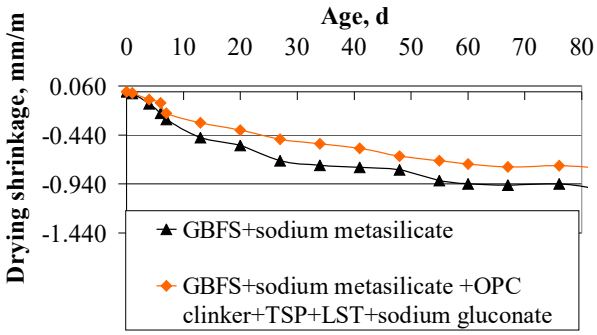

Fig. 2. Drying shrinkage of alkali-activated slag cement fine concrete.

SRA provides deceleration of AASC setting time as well. For example, SRA based on TSP provides prolongation of initial setting time from 45 up to 55 min and final setting time from 60 to 68 min. Increasing strength of modified AASC concrete regarding to the reference one while decreasing W/C ratio from 0.29 to 0.27 was fixed. The tensile strength in bending / compressive strength of the modified AASC concrete: 6.6 / 30.2 MPa (2 d), 6.4 / 41.2 MPa (7 d) i 10.2 / 47.8 MPa (28 d).

The enhancement of AASC concrete properties can be provided not only by water-reducing effect of SRA, but also due to effect on further structure formation. The features of AASC structure, modified by SRA, were fixed by DTA (Fig. 3) and electronic microscopy (Fig. 4, 6) as well as by microzond analysis (Fig. 5, 7).

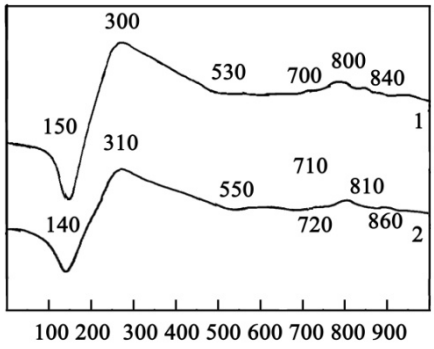

Fig. 3. DTA results of alkali-activated slag cement hydrated during 28 d: 1 – reference; 2 – modified by shrinkage-reducing admixture.

According to DTA, the phase composition of hydrated AASC in absence of SRA (Fig. 3) is represented low-calcium hydrosilicates CSH(B). The endothermic effect at t= 150 °C is determined by their dehydration and exothermic effects at t=840 °C are determined by recrystallization into wollastonite. Endothermic effects at t= 150 and 700 °C (dehydration) and exothermic effect at t= 800 °C confirm formation of slightly crystallized calcium hydrosilicates like gyrolite $2CaO{\cdot}3SiO_2{\cdot}2H_2O$. Slightly crystallized sodium hydroaluminosilicates like gmelinite $(Na_2Ca){\cdot}Al_2Si_4{\cdot}O_{12}{\cdot}6H_2O$ (endothermic effect at

t= 530 °C) are formed in hydration products besides hydrosylicates.

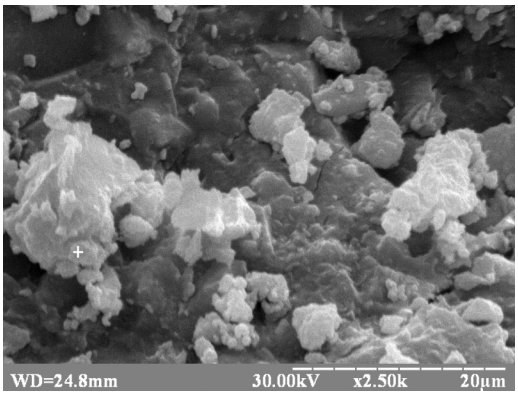

Fig. 4. SEM images of the reference alkali-activated slag cement after 28 d of hydration.

According to electron microscopy (Fig.4), gel-like calcium hydrosilicates (CSH(B), $2CaO{\cdot}3SiO_2{\cdot}2H_2O$) and globular formations of sodium hydroaluminosilicate ($(Na_2Ca){\cdot}Al_2Si_4{\cdot}O_{12}{\cdot}6H_2O$) are identified in the reference AASC (Fig. 5).

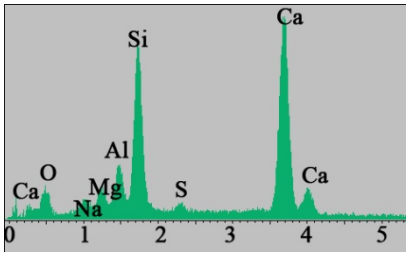

Fig. 5. Probe analysis results of the reference alkali-activated slag cement after 28 d of hydration.

Structure of the modified AASC is represented by hydrates with a higher crystallization in comparison with the reference AASC (Fig. 3). Displacement of exothermic effect from t= 840 to 850 °C is evidence of low-calcium hydrosilicates CSH(B) with higher crystallinity. Displacement of endothermic effect to higher temperature (t= 550 °C) as well as exothermic effect at t= 915 °C ensure formation of gmelinite $(Na_2Ca){\cdot}Al_2Si_4{\cdot}O_{12}{\cdot}6H_2O$ with a higher degree of crystallization.

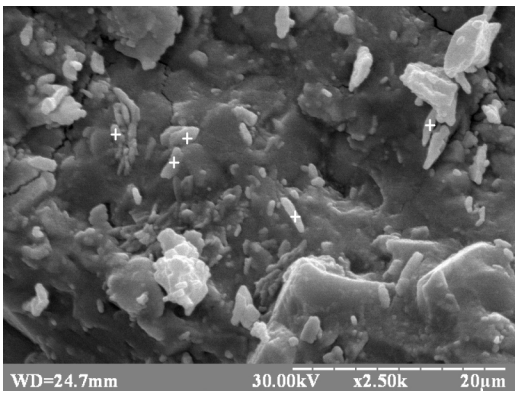

Fig. 6. SEM images of alkali-activated slag cement, modified by shrinkage-reducing admixture, after 28 d of hydration.

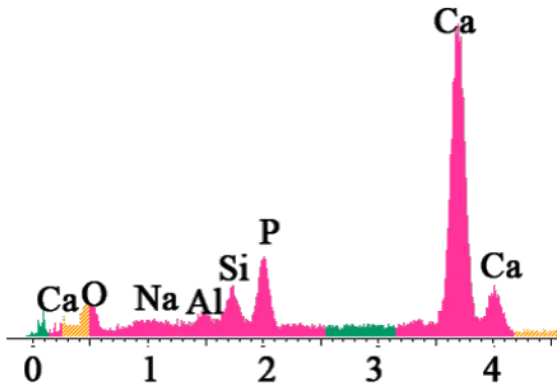

Fig. 7. Probe analysis results of alkali-activated slag cement, modified by shrinkage-reducing admixture, after 28 d of hydration.

The microstructure of modified AASC was investigated. The data indicate hydrosilicates and hydroaluminates with a higher degree of crystallization (Fig. 6) as well as thin plate pyramidal cristalls of hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$ [37] (Fig. 7).

3.2 Enhancement of crack resistance of alkali-activated slag cement concretes based on sodium water glass

The effect of SRA based on TSP and surfactants on enhancement of crack resistance of AASC mortars based on sodium water glass was investigated.

The AASC, modified only by TSP (further, the reference AASC), was characterized by initial setting time – 19 min, final setting time – 21 min. The flexural strength / compressive strength of AASC concrete correspond to values of 4.6 / 25.5 MPa (3 h), 5.0 / 32.3 MPa (1 d), 7.2 / 66.5 MPa (7 d), 8.7 / 86.8 MPa (28 d). The 28 d ratio between tensile strength in bending and compressive strength (further, R_{bend}/R_{comp}) is 0.102.

The initial setting time can be prolonged up to 60 min and the final setting time to 70 min due to modification of the reference AASC by glycerol (2.70 %). SRA composition “TSP – glycerol” ensures water glass, modified by TSP/GBFS ratio diminution to 0.37 due to plasticizing effect. Insignificant deterioration of modified AASC early strength was fixed. Thus the values of flexural strength / compressive strength are: 3.8 / 19.2 MPa (3 h), 5.0 / 29.5 MPa (1 d). However strength of the modified AASC becomes equal to the reference one in 7 and 28 d. The ratio R_{bend}/R_{comp} increases up to 0.140 after 28 d.

Effect of SRA composition “TSP – glycerol – polyacrylamide” on properties of AASC was also researched. The content of glycerol was 2.69 % and polyacrylamide – 0.01 %. This SRA ensures AASC, characterized by initial setting time 58 min and final – 66 min while water glass, modified by TSP/GBFS ratio decreases from 0.4 down to 0.38.

Effects of SRA compositions “TSP – glycerol – polyacrylamide” and “TSP – glycerol” on AASC concrete strength are almost similar. Only insignificant deterioration of early strength was fixed. The flexural

strength / compressive strength of modified AASC concrete corresponds to values of 4.0 / 22.4 MPa (3 h), 5.4 / 31.8 MPa (1 d), 8.8 / 69.0 MPa (7 h), 13.0 / 85.5 MPa (28 d). The ratio R_{bend}/R_{comp} increases up to 0.152 after 28 d. Thus SRA causes maintenance of R_{bend}/R_{comp} ratio on 37-49 % in comparison with the reference AASC concrete. This is evidence of higher fracture toughness as well as crack resistance during late structure formation [51].

The features of AASC structures, modified by SRA of the mentioned compositions, were investigated by electronic microscopy (Fig. 8, 9, 10).

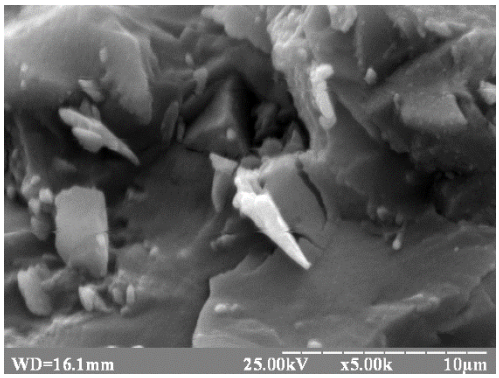

Fig. 8. SEM images of the reference alkali-activated slag cement after 28 d of hydration.

Unlike to the reference AASC (Fig. 8), SRA "TSP – glycerol" ensures increasing volume of hydrates presented by submicrocristalline compounds like spherolites as well as united into agglomerates and block-agglomerates (Fig. 9). SRA composition "TSP – glycerol – polyacrylamide" increases depressiveness of hydrated phases and ensures increasing of phase's boundary area in artificial stone (Fig. 10).

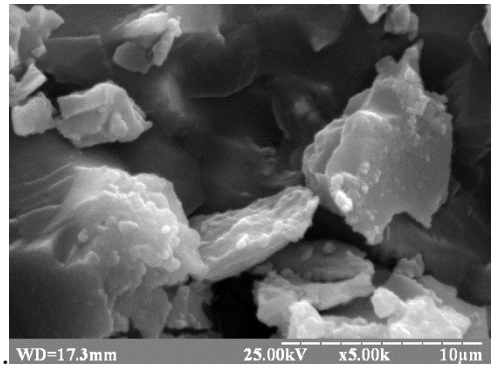

Fig. 9. SEM images of alkali-activated slag cement, modified by shrinkage-reducing admixture composition "trisodium phosphate – glycerol", after 28 d of hydration.

Specified structures of modified AASC concretes testify their higher ability for relaxation and dissipation of outside energy.

Diagrams of AASC mortars elastic-deformed state in co-ordinates "stress – deformations" are shown on fig. 11, 12, 13. Some increasing of rigidity of AASC concrete, modified by SRA's, during initial load stage was fixed. Increasing of tangent angle for AASC concretes, modified by SRA compositions "TSP – glycerol" and "TSP – glycerol – polyacrylamide", in comparison with the reference AASC concrete from 65° (Fig. 11) to 66° (Fig. 12) and 67° (Fig. 13) agreeably confirm this fact.

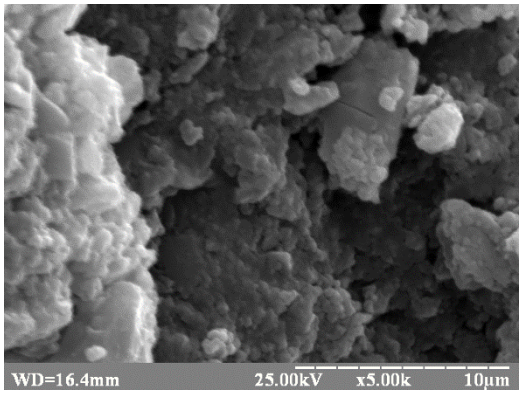

Fig. 10. SEM images of alkali-activated slag cement, modified by shrinkage-reducing admixture composition "trisodium phosphate – glycerol – polyacrylamide", after 28 d of hydration.

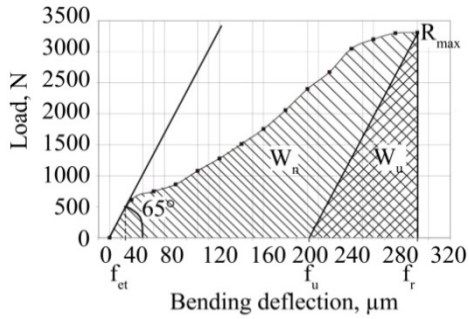

Fig. 11. Deformations of the reference alkali-activated slag cement concrete under load.

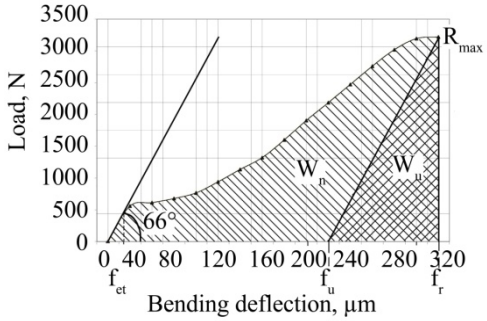

Fig. 12. Deformation of alkali-activated slag cement concrete, modified by shrinkage-reducing admixture composition "trisodium phosphate – glycerol", under load.

SRA ensures higher specific micro cracking (Wn) under subsequent gradual increasing of load until destruction point of samples. Increasing of load resistance for AASC concrete, modified by SRA compositions "TSP – glycerol" and "TSP – glycerol – polyacrylamide" from 3310 N (for the reference AASC concrete) up to 3680 N and 3720 N agreeably was fixed. As well AASC concrete, modified by SRA's, can be characterized by increased specific energy of elastic deformation. Increasing in area of sections W_u by 39-

52 % and maintenance of total bending deflection of samples up to 310 μm confirm this fact.

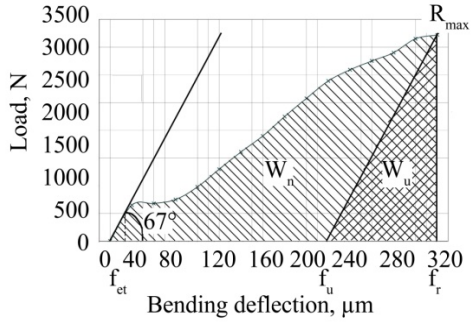

Fig. 13. Deformation of alkali-activated slag cement concrete, modified by shrinkage-reducing admixture composition "trisodiumphosphate – glycerol – polyacrylamide", under load.

Both mentioned SRA's ensure enhancement of fracture toughness, crack resistance and higher ability to deformation of AASC concretes.

Conclusion

1. The crack resistance enhancement of alkali-activated slag cement concretes, based on soluble sodium silicates and obtained from high consistency concrete mixes, was shown from initial up to late stages of structure formation. It was realized due to shrinkage-reducing admixtures based on trisodium phosphate and surfactants. This way the higher crack resistance ensures mitigation of steel reinforcement corrosion.
2. Modification of alkali-activated slag cement fine concretes by shrinkage-reducing admixture composition "ordinary portland cement clinker – trisodium phosphate – sodium lignosulphonate – sodium gluconate" causes less drying shrinkage during early age structure formation and mitigation of drying shrinkage from 0,984 to 0,713 mm/m after 80 d as well as enhancement of crack resistance during late structure formation. Effect of shrinkage-reducing admixtures is caused by reduction of water content and increasing crystallinity of AASC hydrates.
3. Shrinkage-reducing admixtures compositions "trisodium phosphate – glycerol" and "trisodium phosphate – glycerol – polyacrylamide" provide fracture toughness enhancement of alkali-activated slag cement fine concretes during late stages of structure formation. As result, the ratio between tensile strength in bending and compressive strength of AASC concrete can be increased up to 37 – 49 % when water glass is used. At that increasing of bending deflection under load ensures higher elasticity of modified alkali-activated slag cement fine concretes. Specified effects of the shrinkage-reducing admixtures are caused by increasing depressiveness of gel-like hydrates, providing redistribution of stresses in artificial stone and thereby advanced fracture toughness under load.

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Study of the influence of properties of dusty ferromagnetic additives on the increase of cement activity

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Abstract. Sustainable development of construction materials is directly related to research on the processes of hydration of binders. Builders need better types of cement, with lower cost and energy consumption in production. The development of spin chemistry methods allows us to consider the processes of hydration and structure formation of binders from the spin state of the elements involved in chemical reactions. Magnetic interactions have a significant effect on the spin dynamics and the control of the spin multiplicity of radical pairs. The practical implementation of magnetic effects on a binder can be carried out in various ways. However, a long-term impact can be achieved only by introducing ferromagnetic substances into the binders. In the paper presented the results of a study of the influence of the characteristics of finely dispersed powdered ferromagnetic additives on the strength characteristics of cement. Ferromagnetic additives regulate the behavior of the reactants during rotation during the hydration of the binders due to magnetic interactions and control the reactivity of the chemical reaction. A comparative analysis revealed that it is most expedient to use as powdery ferromagnetic additives are the waste from mining and processing enterprises of the Krivorozhsky field. The work investigated the magnetic and dispersed characteristics of 12 different dust. The experiments showed that the origin of dust and the method of their capture are determined their magnetic characteristics. Preparation of samples with the dust and determination of the strength characteristics of cement were carried out by standard methods. The results obtained made it possible to reveal the laws of the effect of the dispersed and magnetic properties of various dust on the degree of activation of binders.

1 The problem and its relationship with scientific and practical tasks

Cement is one of the most essential currently used building materials. The main components for the production of cement are clay and limestone. In the process of co-firing limestone and clay, a clinker obtained consisting of four primary minerals: alite, belite, tricalcium aluminate, and tetracalcium alumino ferrite. Cement is a product of joint grinding of clinker and gypsum, which introduced to regulate the setting time.

After mixing the cement with water, is formed a cement paste, which begins to harden after 40 minutes and finally turns into a cement stone after 6 hours. Cement hardening occurs due to hydrolysis reactions and subsequent hydration of its components. After the influence of water on the surface of cement formed particles of calcium hydroxide, calcium silicate hydrate, and calcium aluminate hydrate. In the process of hardening, neoplasms pass from a colloidal state to a fine crystalline one. Microcrystals gradually grow together. The processes of gel formation, crystallization, and compaction lead to the transformation of cement paste into an artificial high-strength stone material.

The currently existing theories of hardening binders (A. Le Chatelier, V. Michaelis, A. A. Baykov, and others.) primarily develop physicochemical ideas about the mechanism of formation of hydrated compounds and hardening of mixtures of binders with water when they interact with each other. Moreover, the interpretation of the processes occurring during the hardening of the cement paste is based solely on charges. It assumed that during the solidification of binders, the forces of electrostatic nature are decisive since the particles of the new phase are not neutral. Because of the orientation of the dipoles of the dispersion medium adsorbed on their surface, they acquire a particular charge.

Despite numerous studies, this approach has not yet been able to reveal the true nature of the forces leading to the strengthening of the structure and the synthesis of the strength of cement stone and to create a unified and universally accepted theory of hardening of cementitious systems.

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2 Analysis of research and publications

The intensive development of spin chemistry methods allowed us to consider the processes of hydration and structure formation of binders in juxtaposition with the spin state of the elements involved in chemical reactions [1]. In [2], were presented experimental results that prove the presence of radical reactions during the hardening of the cement. In [1, 2] was shown that cement is paramagnetic substances, and the appearance of paramagnetic centers in them explained by the appearance of spin-orbitals populated by a single electron in an atomic or molecular system. The method of electron paramagnetic resonance made it possible to quantify the paramagnetic properties of cement and their change during hardening.

In [5] was shown that the number of paramagnetic centers in cement increases up to 3 days of hardening and then decreases to a level below the initial value. According to the results of studies [3, 4], the concentration of paramagnetic centers in cement is high and can reach 1022 spin/g. The authors found that cement with a higher concentration of paramagnetic centers has higher strength characteristics. Research [5] has shown that cement hardens due to the recombination of paramagnetic centers, which leads to the formation of new phase states, the presence of which contributes to the hardening of the cement mortar and the creation of cement stone.

In [6] was shown that magnetic interactions have a significant influence on the spin dynamics and the control of the spin multiplicity of radical pairs. In this case, magnetic interactions, without affecting the chemical reaction itself, switch it from spin-forbidden channels to spin-allowed ones, regulating the spin behavior of the reagents, replacing non-reaction channels with reaction ones. [6]. Thereby, the reactivity of the chemical reaction is regulated.

It can be argued that magnetic fields can affect the chemical processes that occur during the hydration of binders because of the presence of radical reactions during the hardening of the cement.

Previously it was researched the magnetic activation of water for binder [7], activation of a binder by magnetic treatment during grinding [8], and in the interval between grinding and mixing the binder with water [9].

The method of activation by magnetizing the binder itself [8, 10 – 12] has the disadvantage that.

In most cases have low magnetizability, which also lasts a relatively short time. Thus, this method has a weak effect on the course of hardening reactions of binders.

A method for activating a binder by magnetizing a cement paste has developed in many embodiments. For activation, fields of various intensities were used, as well as variable and pulsating fields. Of all known, this method gives the best results [10] due to the relatively more powerful magnetic fields superimposed on the hardening mixture, as well as the stability of these fields. However, it also has drawbacks that affect the strength characteristics of the binder. First of all, this is a short time of exposure to magnetic fields on the binder. In most cases, it does not exceed 15 to 30 minutes, and this is only a small fraction of the total binder curing time. Accordingly, the effect of activation of the binder decreases.

In addition to the above disadvantages, all of the above methods of activating binders have one more. The binder can be activated only at the place of preparation of concrete or mortar. At the same time, the manufacturing technology of building products is complicated and changed, the time spent on manufacturing specific products increases, the need for additional equipment and specially trained personnel arises, and the likelihood of errors in choosing the magnitude of the magnetic field strength, the time of its exposure and the dosage of additional components increases.

3 Formulation of the problem

The described disadvantages are absent if the binders activated by introducing into their composition a pre-magnetized ferromagnetic powder. The effectiveness of this method because by the fact that the influence of magnetic fields occurs at all stages of the creation of a binder and its hardening, starting from co-grinding cement with powder and ending with long hardening periods of 1 year or more. In this case, each stage contributes to the increase in strength. It is advisable to use powdered ferromagnetic production waste as additives to reduce the cost of activation of binders. As such substances, we proposed the use of dust generated at various stages of iron ore enrichment. At the same time, this allows the disposal of dusty waste from mining and processing plants to sustain the environmental situation. In table 1 is given the characteristics of the enrichment products of various deposits.

Table 1. Characterization of the magnetic properties of concentrates obtained from ores of various deposits [13, 14].

Sample	Density, -10^3 kg/m^3	Magnetization, -10^3, A/m	
		Maximum	Residual
Magnetite of the Akkerman field	4.2	45.7	23.0
Magnetite of the Krivorozhsky deposit	4.7	189.0	60.5
Maghemite of the Vyatka field	4.0	119.0	42.5
Magnetite of the Vysokogorsky deposit	4.8	196.0	22.0
Magnetite of the Lebedinsky deposit	–	80.5	20.0
Magnetite of the Tashtagol deposit	–	64.5	12.5
Magnetite of the Kremenchuk field	–	72.0	22.3
Magnetite of the Sokolovsky deposit	–	105.4	-
Magnetite of the Kachkanarsky deposit	–	126.0	37.0

The table data shows that the largest residual magnetization has the magnetite of the Krivorozhsky deposit. Therefore, the most effective will be the addition of dusty wastes of this field.

In table 2 is shown the chemical and mineral

composition of the dust concentrate from the mining and processing enterprises of Krivbass.

After agglomeration and pelletizing of the concentrate in the dust, the amount of bound calcium oxide and carbon increases. In table 3 is shown the chemical composition of the sinter dust.

Table 2. Chemical and mineral composition of the dust of concentrate of mining and processing plants of Krivorozhsky deposit [13, 14].

	Components	Content
Chemical composition, %	Fe	65.2
	SiO_2	8.17
	Al_2O_3	0.15
	CaO	0.11
	MgO	0.4
	P	0.01
	S	0.014
	other	0.8
Mineral composition, %	magnetite	64.3
	hematite, martite, hydroxides	4.35
	siderite, silicates	2.2

Table 3. The chemical composition of the dust of the sinter machine [15].

Components	Content, %
FeO	9 – 19
Fe_2O_3	45 – 60
SiO_2	6.5 – 10
Al_2O_3	0.5 – 1.5
CaO	6.3 – 9
MgO	0.5 – 1.5
MnO	0.2 – 0.3
P_2O_5	0.03 – 0.05
S	0.2 – 0.5

In table 4 is given the dispersed composition of the dust.

Table 4. The dispersed composition of the dust of mining and processing plants.

Particle diameter, μm	Particle mass, %
4	3.2 – 5.1
4-6.3	2.1 – 2.3
6.3-10	4 – 5
10-16	8.3 – 8.7
16-25	10 – 12
25-40	13 – 15
40-63	12 – 15
63-100	20 – 22.5
100-400	14.3 – 16.2

Research under a microscope shows that particles of iron ore dust are irregular in shape with sharp edges. Most particles have color from brown to black. In the total mass, depending on the stage of enrichment, the color of the dust changes from red to black.

The highest dust formation occurs at the following stages of enrichment: during magnetizing roasting of the ore, during transportation of concentrate, during roasting of pellets, during agglomeration of the concentrate.

Because this, did study four dust groups:

– dust generated by magnetizing roasting of the ore;
– dust generated during transportation of the concentrate;
– dust generated during the firing of pellets;
– dust formed during the agglomeration of the concentrate.

Dust generated after magnetizing roasting of ore during transportation of concentrate and roasting pellets is captured either in cyclones or in an aqueous medium. During dust collection on dust are not superimposed electromagnetic fields. For a complete study of the properties of these dust, it proposed to study them in an unmagnified state and magnetized in a constant magnetic field with a strength of 75 kA/m.

The dust collection of sinter production carried out in electrostatic precipitators. During the capture process, on this type of dust are superimposed high-intensity electromagnetic fields. Given this, the determination of the dust properties of sinter production carried out without additional magnetic treatment.

Each type of dust is assigned a number, which later used on the figures of this article. In table 5 is given the name of dust and their ID number.

Table 5. The identification numbers of different types of dust.

Dust ID number	Type of dust
1	not magnetized dust from the collector generated by magnetizing roasting of the ore
2	magnetized dust from the collector generated by magnetizing roasting of the ore
3	not magnetized dust from the scrubber generated by magnetizing roasting of the ore
4	magnetized dust from the scrubber generated by magnetizing roasting of the ore
5	not magnetized dust of concentrate
6	magnetized dust of concentrate
7	not magnetized dust generated during the firing of pellets
8	magnetized dust generated during the firing of pellets
9	the dust of the sintering machine from cyclone
10	the dust of the sintering machine from electrostatic precipitator zone I
11	the dust of the sintering machine from electrostatic precipitator zone II
12	the dust of the sintering machine from electrostatic precipitator zone III

4 Statement of material and results

The dust research methodology includes the following components: sampling and preparation methods and methods for determining dust properties.

Sampling and preparation of samples carried out according to the following procedure.

A shovel of non-magnetic material used to extract 20 kg of dust from industrial dust collectors. Each sample was placed in its plastic bag and then in an aluminum tank. Then the sample was transported to the laboratory. Further processing of dust was carried out far from sources of electromagnetic radiation.

In the laboratory, the sample was thoroughly mixed and then quartered. Stirring and quartering continued until

the amount of material in the sample were reduced to 100 g. On a sheet of clean white paper of 350×350 mm in size, the sample was mixed and divided into ten equal parts using a plastic spatula.

In one of the formed parts of the dust was immersed a glass rod pre-moistened with glycerin. Then, the stick with adhering dust was placed in a cell with glycerin and mixed until was obtained a homogeneous suspension. Similarly, it was prepared suspensions from the remaining parts of the dust. Each cuvette was alternately placed in the installation to study the properties of dust.

Dust studied in a specially designed setup (Fig. 1) that consists of a digital microscope and a system of electromagnets mounted on a stage. An energy source feeds the orientation coils, as well as the illuminator time relay, so the control circuit provides the simultaneous switching on and off of the coil measurement system and the electronic stopwatch.

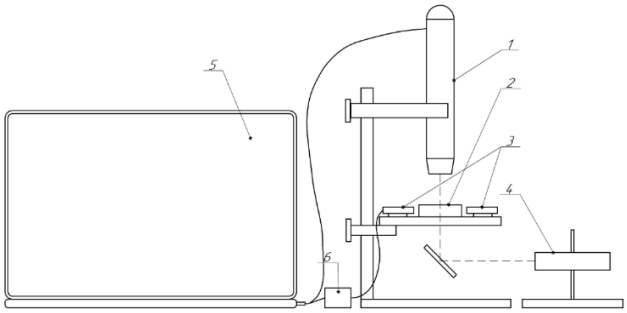

Fig. 1. Installation for determining the magnetic and dispersed characteristics of additives. 1 – digital microscope; 2 – a cuvette with glycerin and dust; 3 – orientation coil system; 5 – laptop with control program; 6 – the digital coil of the power control unit.

A cuvette (Fig. 1) with glycerin and test dust was placed under the microscope lens, after which the orientation system of the coils turned on. In this case, a uniform magnetic field is created in the cuvette, orienting the magnetic particles. Then, using a time relay, the measuring system of coils and the electronic stopwatch are simultaneously switched on. After a particular time, the system turns off.

The rotation angle of all particles is fixed on the photograph at the same speed to eliminate the error of visual observation. First is photographed the arrangement of particles oriented perpendicular to the measuring field along the orientation. Then, using the time relay, the measuring field is switched on for a while and is photographed a new arrangement of particles. Two photographs determine the angle of rotation of particles β, rotation time t, and particle sizes, which makes it possible to decide on magnetic characteristics (Fig. 2). From each sample are determined the parameters of at least one hundred particles.

In the research of dust were determined the fractional composition, the fraction of dust particles with magnetic properties, the average magnetic moment of particles of one fraction, and the average magnetization of all dust.

The dispersed composition was determined by the following fractions: less than 1.4 μm; 1.4 – 4.2 μm; 4.2 – 7.0 μm; 12.6 – 15.6 μm; 15.6 – 31.2 μm; 31.2 – 46.8 μm; 46.8 – 62.0 μm; more than 62.0 μm.

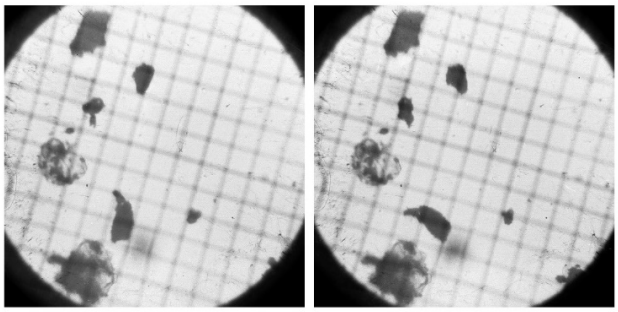

Fig. 2. Dust in the installation for determining magnetic and dispersed characteristics: a) particles in the orientation field; b) particles in the measuring field.

The studies of the characteristics of the dust of magnetizing roasting of the ore used dust taken from the collector during preventive stops of kilns and dust made from the scrubber in the form of a suspension in water. The suspension was precipitated and dried at a temperature of 105-110 ° C to constant weight.

In Fig. 3 and 4 show the disperse and magnetic properties of the dust from kilns taken from the collector, and in Fig. 5 and 6 taken from the scrubber.

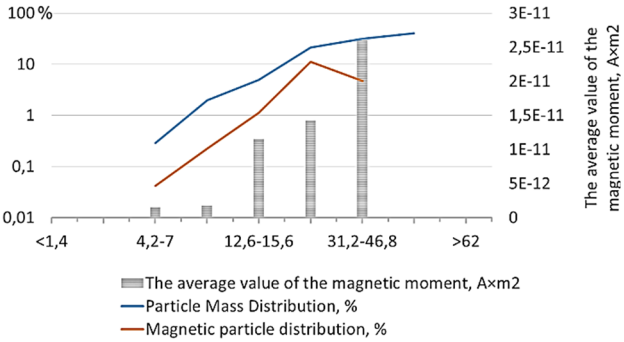

Fig. 3. The disperse and magnetic properties of the not magnetized dust from the collector generated by magnetizing roasting of the ore

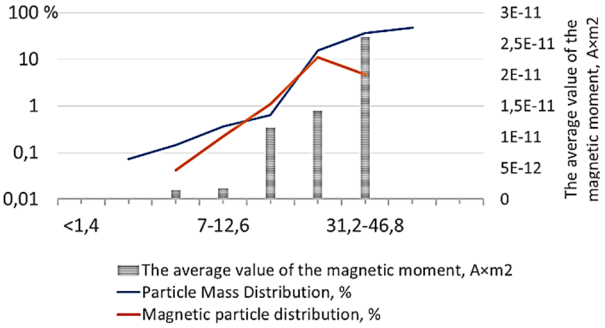

Fig. 4. The disperse and magnetic properties of the magnetized dust from the collector generated by magnetizing roasting of the ore

A comparative analysis of the results shows that the dust taken from the collector has a more significant number of large fractions than the dust made from the scrubber. In the collector, predominantly large particles settle, which are more challenging to carry through the air stream. The dust taken from the collector has an initial magnetization.

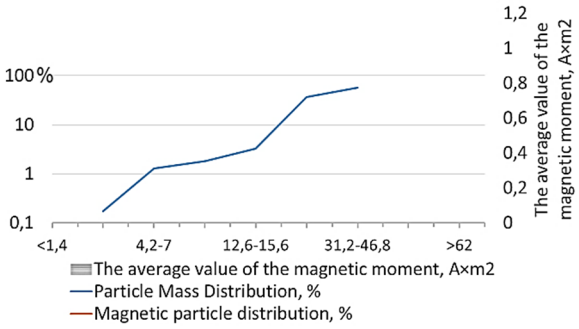

Fig. 5. The disperse and magnetic properties of the not magnetized dust from the scrubber generated by magnetizing roasting of the ore

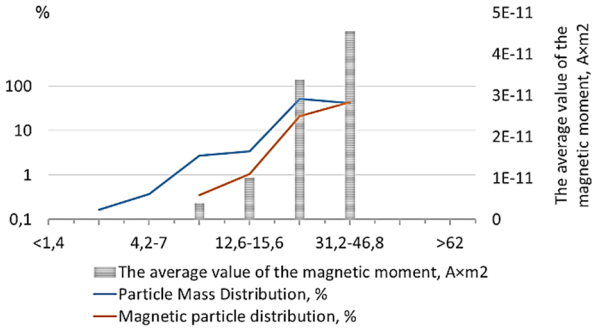

Fig. 6. The disperse and magnetic properties of the not magnetized dust from the scrubber generated by magnetizing roasting of the ore

The dust sampled from the scrubber has no initial magnetization. Because in the dust of the scrubber, there is a higher number of small particles, the temperature of which in the furnace passes through the Curie point. In this case, demagnetization occurs. Large particles have higher thermal inertia and, therefore, do not always have time to demagnetize. Small particles have a large specific surface, therefore, in the process of magnetizing firing, they are better restored, and their magnetic properties increase more. This feature explains the sizeable final magnetization of dust taken from the scrubber.

The studies of the characteristics of the dust generated during transportation of concentrate used the dust sampling from the cyclone hopper. In Fig. 7 and 8 show the results of studies of the dispersed and magnetic properties of dust.

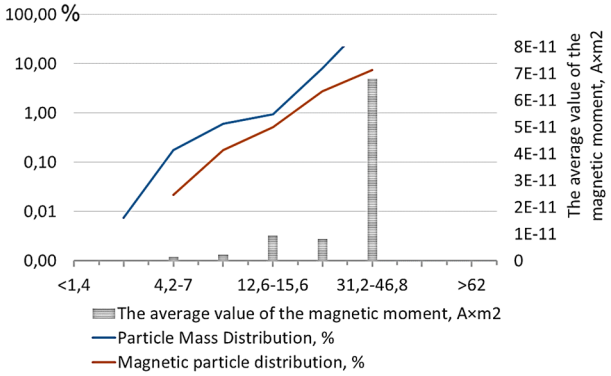

Fig. 7. The disperse and magnetic properties of the not magnetized dust of concentrate

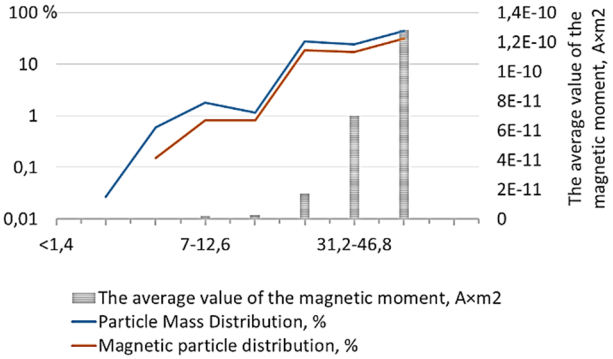

Fig. 8. The disperse and magnetic properties of the magnetized dust of concentrate

An analysis of the results shows that a significant proportion of the magnetic substance in the dust of concentrate is 97% versus 42% for the dust from the kiln. This circumstance, as well as the fact that the enriching of the ore is by strong magnetic fields, determines the high initial and final magnetization of this type of dust.

The studies of the characteristics of the dust generated during the firing of pellets used the dust sampling from the outer hatches of the cyclone hopper. Dust formed because of the impacts of the pellets against each other and the wall of the kiln. Therefore, a higher number of finely dispersed particles with significant magnetization and initial magnetization appear. The research results are shown in Fig. 9 and 10. An analysis of the results shows that a high average dust magnetization (4.5 kA/m) created by large fractions (23.4-54.6 μm). However, particles less than 15.6 μm in size have the greatest magnetization (up to 30 kA/m). A difference in the magnetization of the particles of the 2.8 μm fraction in the magnetized and non-magnetized state noted this is because of the temperature transition of these particles during firing through the Curie point.

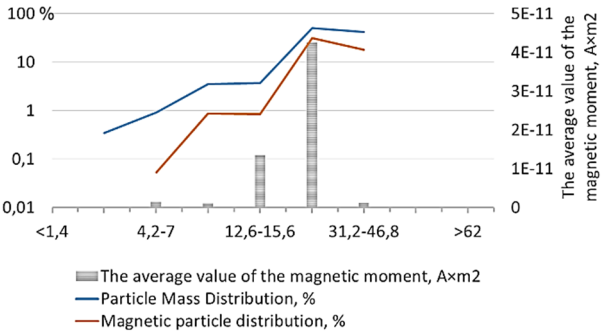

Fig. 9. The disperse and magnetic properties of the not magnetized dust generated during the firing of pellets

The studies of the characteristics of the dust of the sinter machine used the dust sampling from the cyclone hopper, as well as from electrostatic precipitators during the preventive stop of the sinter machine. In Fig. 11 – 14 show dust research results.

A comparison of the results shows that the dust selected from the III zone of electrostatic precipitators has the smallest average size and the largest residual magnetization. From cyclone to zone III, the fraction of magnetized particles, as well as their remanent magnetization, increases in each dust fraction. From the

cyclone to III in each zone increases the proportion of magnetized particles fractions of dust and their remanence. This feature explained by the fact that when moving at a higher speed in an inhomogeneous electric field, the particles experience the action of a magnetic field. Because of this, the magnetization of dust occurs.

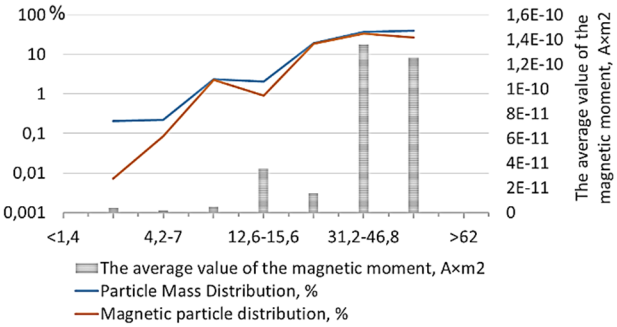

Fig. 10. The disperse and magnetic properties of the not magnetized dust generated during the firing of pellets

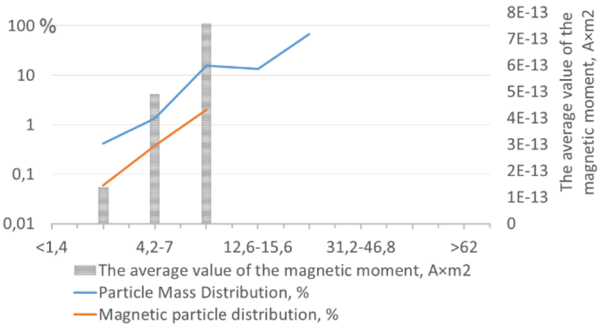

Fig. 11. The disperse and magnetic properties of the dust of the sintering machine from cyclone

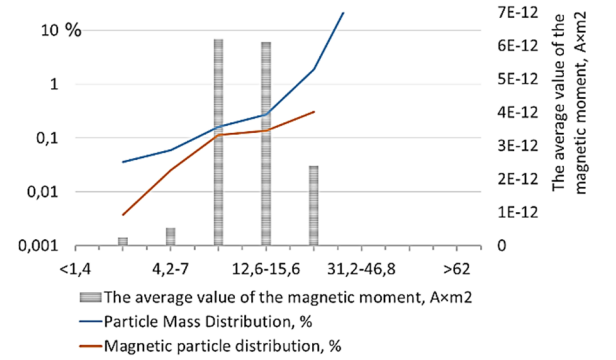

Fig. 12. The disperse and magnetic properties of the dust of the sintering machine from electrostatic precipitator zone I

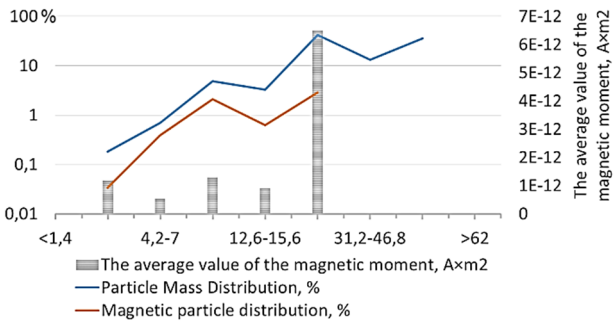

Fig. 13. The disperse and magnetic properties of the dust of the sintering machine from electrostatic precipitator zone II

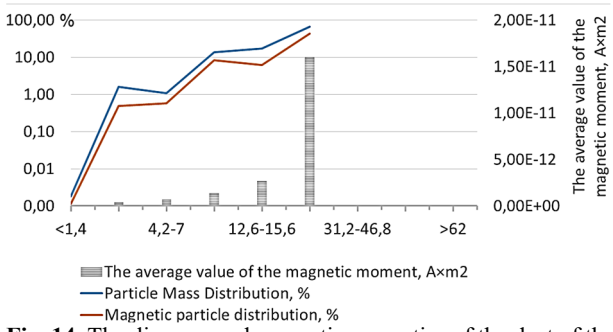

Fig. 14. The disperse and magnetic properties of the dust of the sintering machine from electrostatic precipitator zone II

In Fig. 15 – 16 shown the comparative characteristics of all investigated dust. It is known that when mixing solids, the uniformity of the mixture increases with a decrease in the size of its constituent particles. Most of the studied dust consists of particles with a size of 31.2 – 62.0 μm (Fig. 3). Only for agglomeration dust from the III zone of the electrostatic precipitator, the bulk of the particles have a size of 12.6-31.2 μm. When mixed with cement, this dust allows getting the most uniform distribution of particles in the binder.

Researches show that after magnetization in the dust, the proportion of largess particles increases due to smaller ones. The study of this phenomenon showed that this is due to the aggregation of magnetized particles.

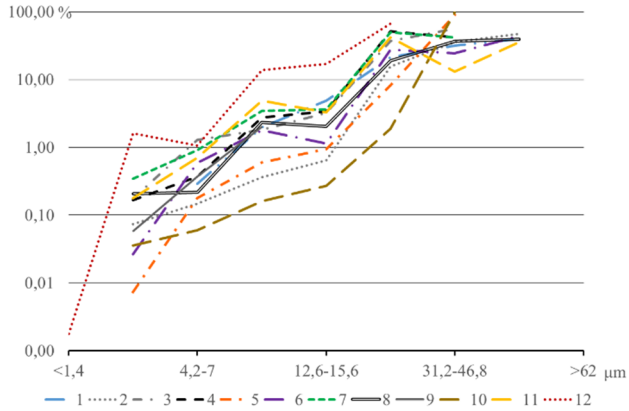

Fig. 15. Fractional composition of the dust. Dust numbers correspond to table 5.

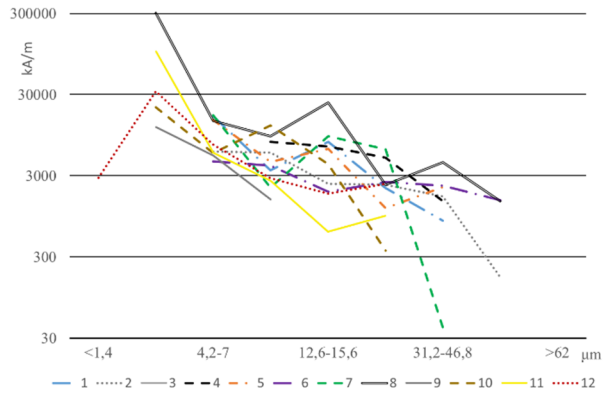

Fig. 16. The average value of the magnetization of dust by fractions, kA/m. Dust numbers correspond to table 5.

The magnetic field strength decreases in proportion to the distance from the source. Calculations show that an

increase in the size of dust particles at a constant concentration in the binder increases the distance between the dust particles, the sources of the magnetic field. Increases of the distance create an uneven magnetic field inside the binder and, accordingly, an inhomogeneous activation effect. On the contrary, a decrease in the size of dust particles leads to a decrease in the distance between the magnetic field sources and an increase in the quality of the activation effect. The majority of particles with magnetic properties in most dust have a size of 31.2 – 62.0 μm.

The most significant part of the magnetic particles in the dust of the sintering machine has a size of 12.6 – 31.2 μm, and the fraction 1.4 – 12.6 μm from the III zone of the electrostatic precipitator accounts for more than 13% of all magnetic particles. This fact allows us to conclude that using the dust of the sintering machine from zone III of the electrostatic precipitator as an activating additive can be achieved the highest uniformity of magnetic fields in cement.

The methodology used to study the properties of dust used in this work makes it possible to determine the contribution of each fraction to the creation of a magnetization. Studies have shown that the magnetization of dust particles increases with decreasing particle size. The dust is polymineral and contains in its composition both components with and without magnetic properties. During particle fragmentation, the destruction occurs primarily along the cleavage planes of grains having differences in magnetic properties. As a result, either particle having high magnetic characteristics or not having them at all formed.

It is characteristic of the studied dust that with a decrease in the size of the fractions, the fraction of dust particles with magnetic properties decrease. However, the large magnetization of fine dust is the reason that a decrease in the proportion of magnetic particles does not correspond to a decrease in magnetization. For example, in agglomeration dust from the III zone of electrostatic precipitators, the proportion of particles with a size of 1.4 – 12.6 μm having magnetic properties is 5.2% of the total mass of dust, and their contribution to the total magnetization is 15.3%.

In most dust, particles of 12.6 – 62.0 μm is made the main contribution to the creation of magnetization (Fig. 4).

Dust of the sintering machine from electrostatic precipitator zone III creates the bulk of the magnetization by particles of 1.4 – 31.2 μm in size, which is a prerequisite for obtaining a high activation effect.

The averaged values of the magnetic and dispersed properties of the dust required for further studies shown in Fig. 17 and 18.

If the mean diameter of dust particles, their mass and mass fraction in the mixture is known, assuming that the particles located in the mix at the same distance, we can calculate the average length, r_{mean} between dust particles in the mixture with cement.

In total, were studied 12 dust with various combinations of magnetic and dispersed characteristics. Since other characteristics of dust differ little from each other, the obtained results allow us to conduct studies to identify the general laws of the influence of various dust on the activation of a binder.

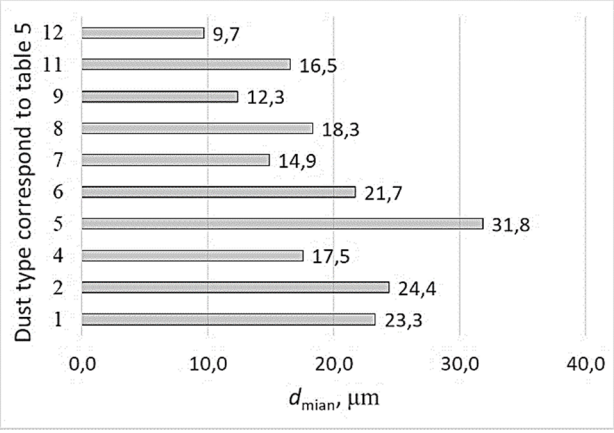

Fig. 17. The mean diameter of different types of dust.

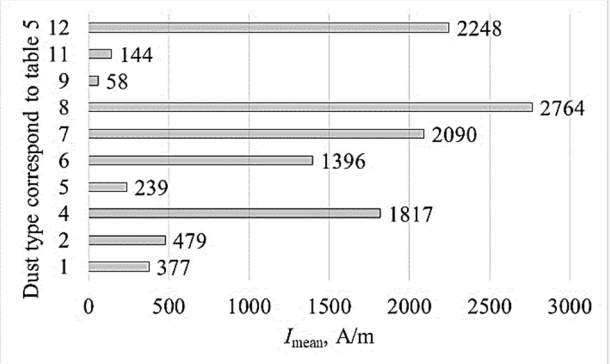

Fig. 18. The mean magnetization of different types of dust.

The average diameter of the largest of the studied dust is 2.5 times larger than that of the smallest. The minimum and maximum values of the average magnetization of different dust differ by more than 40 times.

Processing of the obtained data has shown the relationship between the activity of binders and the magnetic and dispersed characteristics of the introduced additives. In studying were investigated the strength characteristics of cement-sand mortars made from binders containing 98% of blast furnace cement and 2% of one of the dust. Mixing cement with the additive was carried out in a ball mill for 8 minutes. Further tests were carried out by DSTU EN 196-1:2007. In table 6 and Fig. 19 – 20 show the test results.

Processing of the results showed that the increase in strength correlates with the average distance between particles and the magnetization of dust. Dependencies are:

$$R_m = 5,376 + 0,0012\left(\frac{I_{mean}}{r_{mean}}\right) \quad (1)$$

$$R_c = 37,84 + 0,028\left(\frac{I_{mean}}{r_{mean}}\right) \quad (2)$$

Correlation coefficients for (1) – K_{cor} = 0.913 with a standard error of 0.07, for (2) – K_{cor} = 0.911 with a standard error of 1.7.

Reducing the size of dust particles affects the activation effect in two ways: firstly, the uniformity of mixing of particles increases, which improves the uniformity of magnetic fields induced by dust, and

secondly, with decreasing particle size, their magnetization increases, which also increases the activity of binders.

Table 6. The dependence of the characteristics of cement-sand mortars on the properties of the introduced iron dust.

Type of input dust	The mean distance between particles in the mixture r_{mean}, μm	$\frac{I_{mean}}{r_{mean}}$	R_m, MPa	R_c, MPa
No additives			5.26	33.45
Not magnetized from the collector	14.8	25.5	5.42	37.36
Magnetized from the collector	15.4	31.0	5.46	38.39
Magnetized from the scrubber	11.1	163.5	5.52	42.22
Not magnetized dust of concentrate	20.2	11.9	5.31	39.2
Magnetized dust of concentrate	13.8	101.4	5.54	43.67
Not magnetized dust of the sintering machine	9.4	221.8	5.52	42.22
Magnetized dust of the sintering machine	11.6	238.0	5.75	46.92
From cyclone	7.8	7.4	5.37	36.72
From electrostatic precipitator zone II	10.5	13.7	5.43	37.95
From electrostatic precipitator zone III	6.1	366.9	5.81	47.34

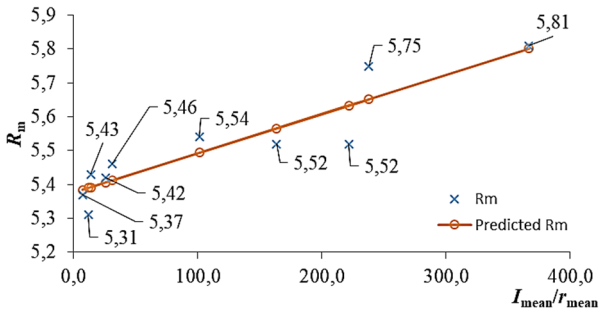

Fig. 19. Effect of dust characteristics on cement bending strength.

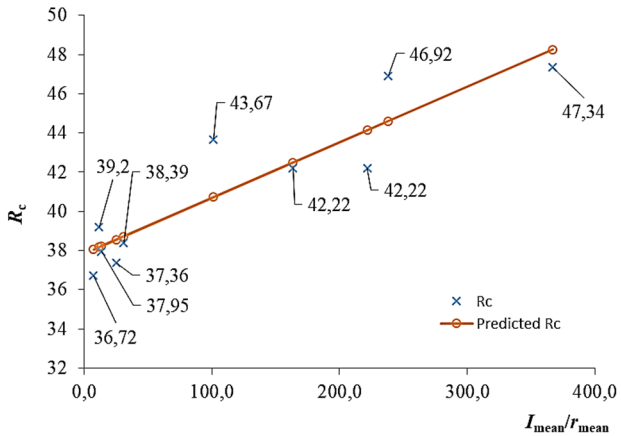

Fig. 20. Effect of dust characteristics on cement compressive strength

It follows that the most significant activation effect achieved by introducing iron-containing magnetized dusty substances into the binder, in which the ratio I_{mean}/r_{mean} is of the highest importance. Among those considered, this is the dust of the sintering machine taken from electrostatic precipitator zone III. Its activation effect, along with magnetized dust from the kiln, is 41%. However, unlike the latter, dust from the III zone of the electrostatic precipitator does not need magnetization.

5 Conclusions

The studies show that the magnetic characteristics determined by the origin and method of dust collection. Studies revealed that with decreasing dust particle size, their magnetization increases. After additional magnetization, the fractional composition of dust changes due to the aggregation of small parts into large ones.

The studied dust has 12 different combinations of magnetic and dispersed characteristics, which is enough to identify the patterns of the influence of each of the factors on the activity of binders.

In studies was established that from the studied dust, the highest uniformity of magnetic fields in the binder allows getting dust from the III zone of the sinter machine electrostatic precipitators.

The investigation established that the introduction of pre-magnetized ferromagnetic dust into the composition of blast furnace cement has an activating effect on the process of binder hydration.

Studies proved that the degree of influence of the additive on the binder activity depends on the distance between the dust particles and the magnetic field strength.

In the future, it is necessary to study the processes of structure formation under the influence of a ferromagnetic additive and their influence on the strength and deformation characteristics of mortar and concrete.

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Comparative analysis of strength and deformation of reinforced concrete and steel fiber concrete slabs

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Abstract. The results of experimental studies of the steel fiber influence on the bearing capacity, deformability and crack resistance of reinforced concrete multi-hollow plates are given. We investigated a serial floor slab and a similar one, but with the addition of steel fiber. Both plates are factory-made. For testing, the testing apparatus was designed and manufactured that made it possible to study full-size floor slabs in laboratory conditions. The tests were carried out according to a single-span scheme with the replacing equivalent load. The loading was carried out by applying two concentrated strip vertical loads along the plate width. The load was applied in steps of (0.04 ÷ 0.05) from the breaking load. Each stage ended with exposure lasting up to 10 minutes with fixing all the necessary parameters. Deformations were measured using dial gauges. From the moment the first crack appeared in the stretched zone of concrete, the process of crack formation and opening was monitored. At each level, using the Brunell tube, the width of their opening and height were measured. The moment of cracking in both slabs began at the same relative strain. It has been established that the bearing capacity and crack resistance of a slab of combined reinforcement using steel fiber are respectively 50 and 44% higher than that of a similar reinforced concrete slab. The maximum deflection of the slab of combined reinforcement is 37.5% lower than that of conventional reinforced concrete. The destruction of both slabs occurred under loads, when the relative deformations in the compressed zone of concrete reached 0.80×10^{-3} and 1.10×10^{-3} for reinforced concrete and steel-fiber concrete slabs, respectively, the difference is 37.5%.

1 Introduction

Hollow core slabs are usually used as slabs between floors in the construction of buildings and structures. Of various shapes and sizes, with different bearing patterns, they are all widely used in construction. Their production accounts for a significant mass part of reinforced concrete of the total material consumption during the construction of the facility. This type of product can be called universal, because its use is not limited to the type of structure. The main distinguishing feature of such floor slabs is the presence of voids located along the slab. These voids almost always have a circular cross section. Also, characteristic is the manufacture of recessed grooves along the side faces. Such plates are pre-stressed and non-stressed by pouring into molds and subsequent vibration compaction with final heat treatment.

The improvement of such demanded reinforced concrete structures, the increase in their bearing capacity, crack resistance and durability is an actual problem.

2 Recent researches analysis

It is known that the use of steel fiber leads to an increase in the physicomechanical characteristics of concrete, namely, strength, deformability, crack resistance, water permeability, impact strength, frost resistance, etc. [1-3].

Most of these characteristics are usually determined in the laboratory. In this case, the main objects of research are samples in the form of cubes or prisms, and less often – models in the form of beams or slabs of reduced size.

Over the past five years, the authors have carried out large-scale studies to determine the effect of steel fiber on the strength and deformation properties of fiber concrete [4, 5]. It was found that the strength and crack resistance of steel fiber concrete, higher than that of ordinary concrete, on average, by 40 and 30%, respectively. Creep – on the contrary, is (20-22)% lower. The long-term strength of steel fiber-reinforced concrete beams that have been exposed to operational loads for more than 400 days is on average 37% higher than that of similar beams made of ordinary concrete. All these results were obtained, again, in laboratory conditions, and, as it is known, they are far from always confirmed by the operation of real structures.

Studies to expand the scope of steel fiber concrete are carried out by many authors [6-8]. So, in [9], the use of fiber-reinforced concrete slabs is considered, which are more economically and technically profitable compared to conventional reinforced concrete slabs when installing floors. The author substantiates this by an increase in impact strength and ductility, higher crack resistance and bearing capacity. An interesting comparison of the

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properties of concrete slabs with two types of fiber fibers and in the absence of fiber reinforcement was presented in [10]. Four specimens contained steel and polypropylene fibers added in a volume ratio of 0.5% and 1.0%. The slabs had dimensions of 820 × 820 × 80 mm and were supported by four rollers along the edges that control the displacement. The concentrated load is applied in the center of the plate. The results of experimental studies were compared with theoretical predictions. Based on the processing of the data obtained, it was concluded that 1% of steel fibers by volume has the best effect on the operation of the slabs. This conclusion coincides with our results regarding the effectiveness of fiber reinforcement.

A. Blanco [11] believes that combining fibers with traditional reinforcement can be a very interesting design decision to create more durable and economical designs. His work is devoted to the analysis of the bearing capacity and ultimate state of slabs. For this purpose, eighteen concrete slabs (3 × 1 × 0.2m) with different reinforcement, fiber types (steel and plastic) and their volumetric content (0.25 and 0.50%) were investigated. These slabs were tested for bending with data monitoring at four points.

The works of other authors can be noted [13-14], but nevertheless, the influence of steel fiber on the work of flexible concrete elements has not been fully studied, and many aspects of practical interest remain.

3 The purpose of work

The aim of this work is an experimental study of the influence of steel fiber on the bearing capacity, deformability and crack resistance of serial reinforced concrete multi-hollow slabs manufactured in the factory.

4 Materials and methods

The object of the study are floor slabs PK 30.12-8, manufactured in the factory by the enterprise Velikodolinsky ZhBK Plant, LLC in accordance with regulatory documents [15, 16] and working drawings of the 1.141-1 series [17], using conventional technology and with the addition of steel fiber with curved ends.

For testing, a testing apparatus was designed and manufactured that made it possible to study full-sized floor slabs in laboratory conditions (Fig. 1). In order to comply with safety regulations and prevent brittle collapse of reinforced concrete slabs during the test under load, steel pipes were freely threaded into the extreme voids, which did not impede the deformation of the structure. This made it possible to timely detect the appearance of cracks, safely measure their parameters and draw on the underside of the slab.

Fig. 1. Testing apparatus.

To determine the strength properties of concrete, at the factory, samples of cubes with a rib size of 10 cm were made from the same mixture as the slab, which were tested for compression in laboratory conditions. The obtained value of cubic strength showed that concrete corresponds to grade C16/20. Determination of concrete strength during short-term loading was carried out in accordance with the requirements of current standards [18, 19].

The tests were carried out according to a single-span design with a substitute equivalent load (Fig. 2). The loading was carried out by applying two concentrated strip vertical loads along the slab width.

5 Research results

Two multi-hollow floor slabs were tested, one is ordinary reinforced concrete (PK series 30.12-8), and the second is similar, but with the addition of 1% steel fiber. Slabs have dimensions in the plan of 1190x2980 and a height of 220 mm (Fig. 3), concrete consumption 0.43 m^3.

During the tests, the load applied to the element and the corresponding deformations were recorded; tests were carried out in accordance with [20].

The load was applied in steps of (0.04 ÷ 0.05) from the breaking load. Each stage ended with exposure lasting up

to 10 minutes with fixing all the necessary parameters. Deformations were measured using dial gauges with a division price of 0.001 mm and a base of 25 cm. Five gauges (3, 4, 5, 6, and 7) were installed on the upper surfaces of the slabs, in the central part (Fig. 3). Gauges 1, 2 and 8, 9 were fixed to the side surfaces (faces) of the plates. The first two gauges were located in the middle of the span in the zone of clean bending, and a pair of indicators 8, 9 in the zone of load transfer (Fig. 3). The first and ninth gauges are in the stretched zone of concrete, 2 and 8 are in the compressed.

From the results shown in Fig. 4 and 5, it follows that the readings of all 5 gauges located on the upper surfaces of the slabs from the beginning of loading and up to failure change equally synchronously and almost by the same value. The latter indicates that the loading of reinforced concrete slabs using a two-level cross-beam system ensures uniform loading of its upper surface.

From the moment the first crack appeared in the stretched zone of concrete, the process of crack formation and opening was monitored. At each level, using the Brunell tube, the width of their opening and height were measured.

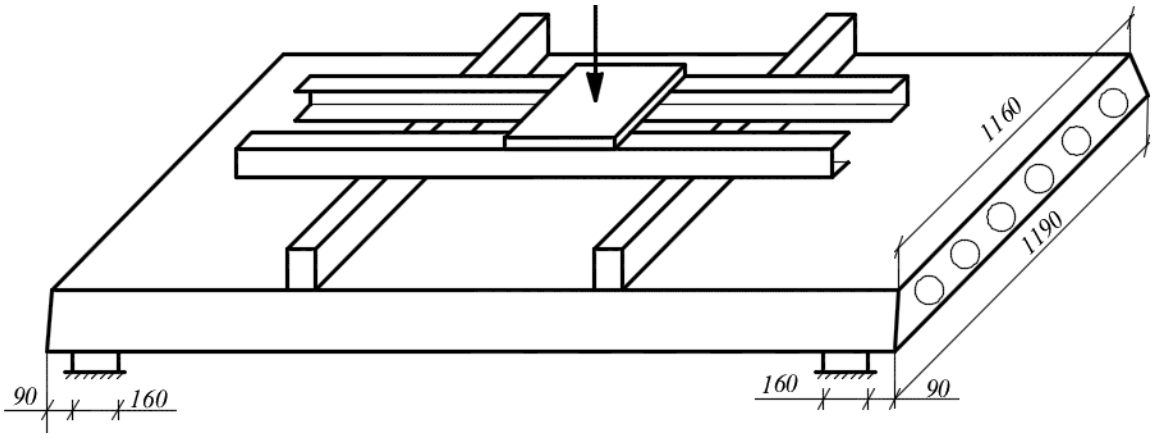

Fig. 2. Loading concept.

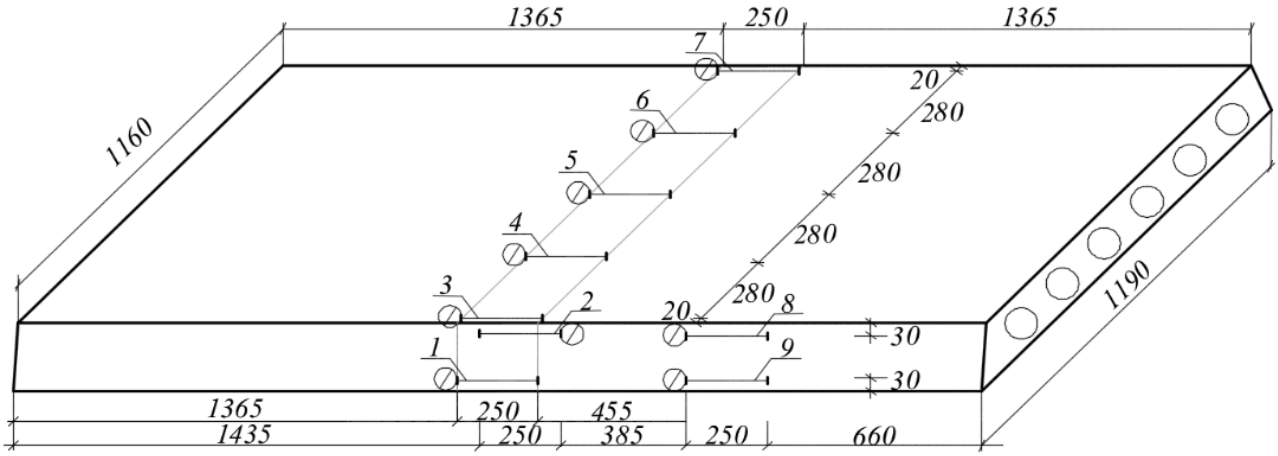

Fig. 3. Indicator layout.

Fig. 4 shows the nature of the deformations obtained in the process of loading a reinforced concrete floor slab. From the results shown in the figure, it can be seen that three sections can be distinguished on the deformation curves.

I section. Up to a load level of 44.41 kN, corresponding to the beginning of crack formation, a linear relationship is observed for all concrete fibers. The values of relative deformations in the compressed and stretched zones are almost the same ($\varepsilon = 0.1\times10^{-3}$).

II section. At VIII-X loading steps, when the load varies in the range from 44.41 kN to 59.21 kN, a sharp change in the strain growth rate occurs (the angle of inclination of the curves changes significantly). Deformations in the compressed and stretched zones of concrete increase almost 3 times. Such a significant increase in deformation is explained by the avalanche-like process of cracking (12 cracks with an opening width of up to 0.005 mm).

In section III, with a load of more than 59.21 kN, the relative deformations in the compressed zone of concrete again change almost linearly up to the breaking load (108.55 kN) and amount to 0.75×10^{-3}. In the stretched zone of concrete, the strain growth rate is significantly higher. Deformations from 0.2×10^{-3} increased to 1.4×10^{-3}, 2 times higher than the deformation of the compressed

zone of concrete. This is explained by the fact that, at this stage of loading, along with the formation of new cracks, the process of opening previously formed cracks is intensified. The width of their disclosure increases 3-4 times.

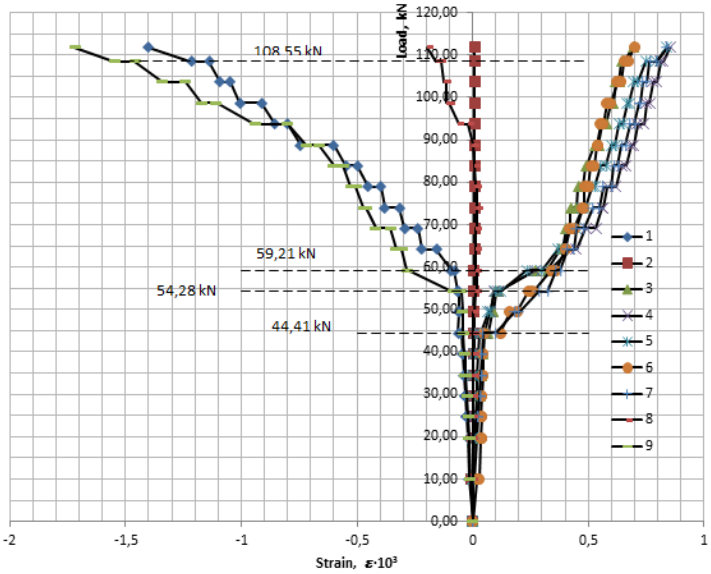

Fig. 4. Deformation of a hollow-core reinforced concrete slab according to indicators.

Figure 5 shows the deformation of concrete fibers in a steel-fiber concrete slab.

The nature of the curves shown in Fig. 5 is similar to the nature of the strain curves of concrete fibers in a conventional reinforced concrete slab (Fig. 4). Namely, a linear relationship is observed up to the load level corresponding to the onset of crack formation (64.14 kN). Relative deformations corresponding to the indicated load do not exceed the value of 0.1×10^{-3}.

The latter indicates that the cracking moment in both slabs begins at the same relative strain equal to 0.1×10^{-3}.

At the second stage, in the range of load changes from 64.14 kN to 78.95 kN, the relative deformations in the compressed zone of concrete increase to 0.2×10^{-3}, which is two times lower than in a slab of ordinary reinforced concrete. This is explained by the fact that 12 cracks formed in an ordinary slab at this stage, and in a slab of steel-fiber-reinforced concrete – 7. Moreover, not only the number of cracks, but also the width of their opening is 1.7 times smaller.

In the third section, at loads greater than 78.95 kN, the relative deformations in the compressed zone of concrete again change linearly up to a breaking load of 162.83 kN.

Comparing the results shown in Fig. 4 and 5, it is easy to verify that the destruction of the investigated plates occurred when the relative deformations in the compressed zone of concrete reached 0.80×10^{-3} and 1.10×10^{-3} for reinforced concrete and steel-fiber concrete plates, respectively; the difference is 37.5%.

In a reinforced concrete slab, this deformation occurs at a load of 108.55 kN, and in a steel-fiber concrete slab at 162.83 kN; these values differ by 50%.

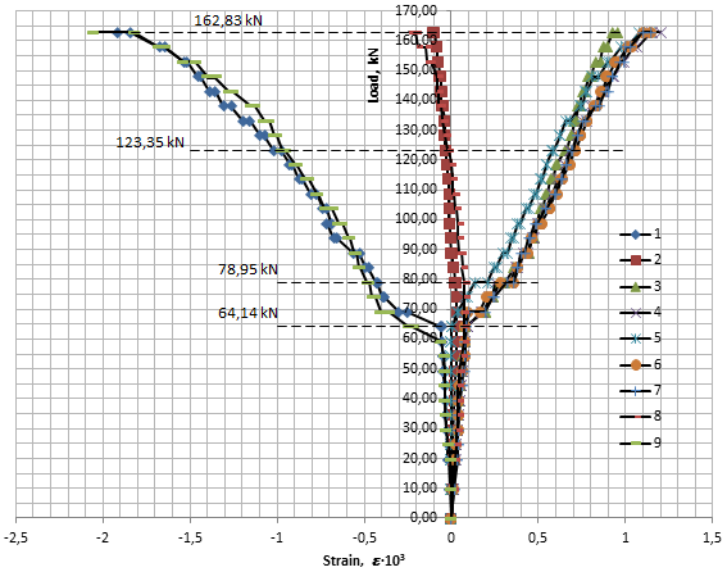

Fig. 5. Deformation of a hollow-core steel fiber concrete slab according to indicators.

Figure 6 shows the nature of the changes in the deflection of a reinforced concrete slab during its loading. Deflections were measured using the Maximov deflections with a division value of 0.01 mm. The results presented in Fig. 6 are identical to the results shown in Fig. 4, in the sense that the previously described stages of structural deformation are clearly traced on the curves.

Stage I to the load level of 44.41 kN (41% of the destructive) – linear. The maximum deflection at the end of the stage is 1.7 mm, i.e. 7% of its maximum value at the destruction moment.

At stage II, the linearity is substantially violated, and by the end of the stage, the deflections increase to 5.5 mm, i.e. more than 3 times with an increase in load of only 10%. This is also explained by the fact that 12 cracks formed in the plate at this stage.

At stage III, the load compared to the first two stages doubled, and the deflections increased five times to a value of 2.5 cm.

In Figure 7 shows the nature of the change in deflections in a steel-fiber concrete slab during its loading. In this figure, as in the previous ones, 3 sections can be distinguished. The first one is linear up to the load level corresponding to the moment of crack formation (64.14 kN).

At the second section, in the load interval from 64.14 kN to 123.35 kN, linearity is broken, because 19 cracks with an opening width not exceeding 0.005 mm are formed.

In the third section, the load varies from 123.35 kN to 162.83 kN. The process of formation of new cracks is significantly slowed down (5 new cracks), and in parallel with it, the process of intensive opening of existing cracks begins. The width of the opening of five cracks increased 10 times (0.05 mm).

Figure 8 shows for comparison the deflections in reinforced concrete and steel fiber concrete slabs. From the presented results it is seen that the maximum deflection in a steel-fiber concrete slab is 37.5% less than in a similar reinforced concrete slab.

This is explained by the fact that at the time of fracture in a conventional reinforced concrete slab there were 8 through cracks with an opening width of up to 0.1 mm, while in a steel fiber reinforced concrete slab there were only 4 with an opening width not exceeding 0.06 mm. In addition, the total magnitude of the opening of all cracks in an ordinary slab is 1.57 mm, and in steel-fiber concrete – only 0.52 mm, i.e., almost 3 times less.

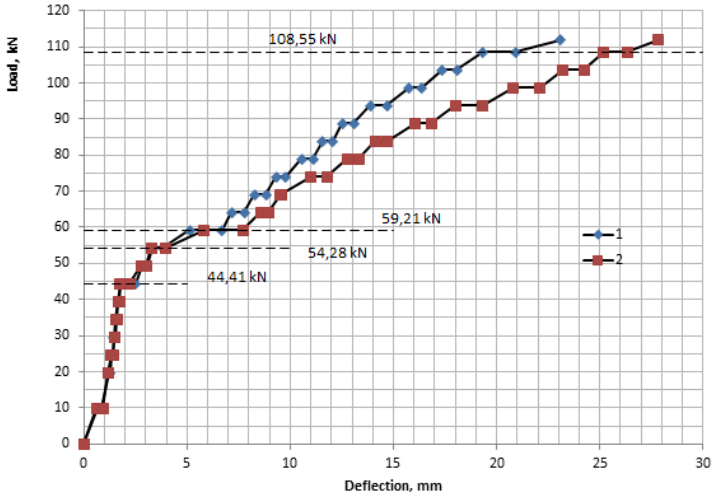

Fig. 6. Deflection of a reinforced concrete slab in the center of the span according to the readings of two deflection meters.

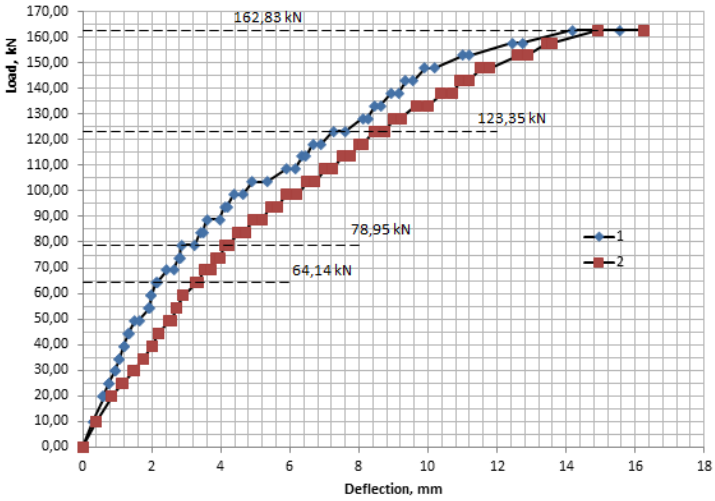

Fig. 7. Deflection of a steel fiber concrete slab in the center of the span according to the readings of two deflection meters.

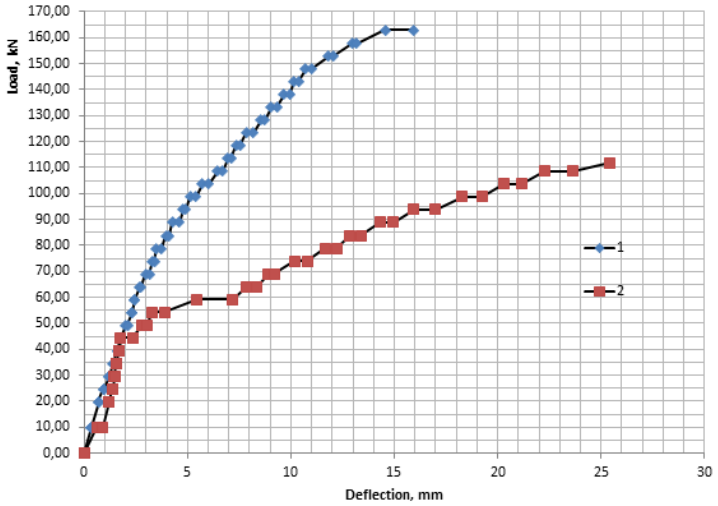

Fig. 8. Deflections of hollow-core slabs in the center of the span 1 – steel fiber concrete slab, 2 – reinforced concrete slab.

Along with indicators, strain gauges with a strain measurement base of 50 mm were glued on the upper and lateral surfaces of reinforced concrete and steel fiber reinforced concrete slabs (Fig. 9). The results presented in Fig. 10, indicate that two completely unrelated strain measurement systems show very close values (the difference does not exceed 5%).

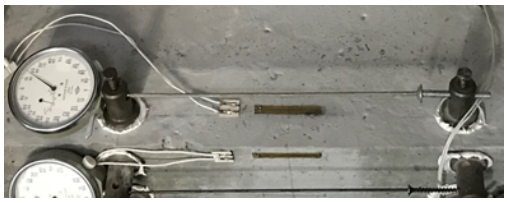

Fig. 9. The location of the strain gauges under the indicator.

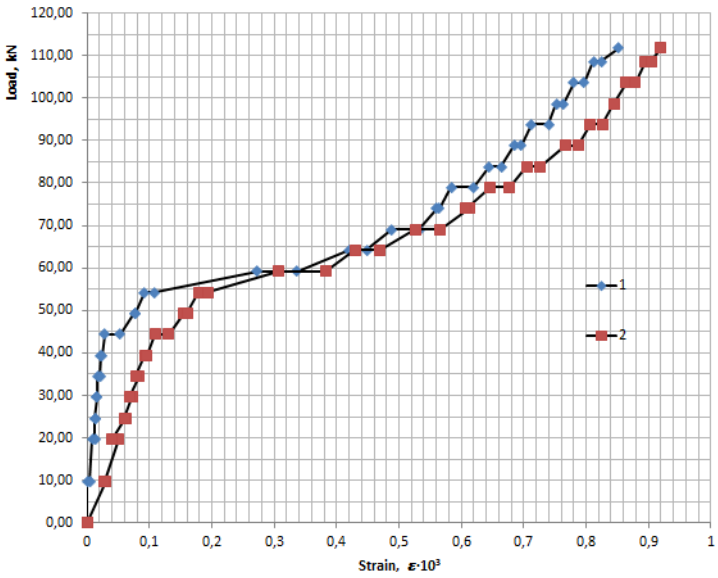

Fig. 10. The deformation of the longitudinal fibers of the upper side of the plate according to the indications of the indicator and strain gauge: 1 – according to the indications of the indicator, 2 – according to the indications of the strain gauge.

6 Conclusions

An analysis of the experimental studies showed that the main parameters that determine the physicomechanical characteristics of concrete and fiber-reinforced concrete, namely, bearing capacity, deformability and crack resistance, are interconnected throughout all stages of loading.

1. The bearing capacity and crack resistance of a slab of combined reinforcement using steel fiber are respectively 50 and 44% higher than that of a similar reinforced concrete slab.
2. The maximum deflection of the slab of combined reinforcement is 37.5% lower than that of ordinary reinforced concrete.
3. The destruction of both slabs occurred under loads, when the relative deformations in the compressed zone of concrete reached 0.80·10-3 and 1.10·10-3 for reinforced concrete and steel-fiber concrete slabs, respectively, the difference is 37.5%.

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Stability of orthotropic plates

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Abstract. The solution to the problem of the stability of a rectangular orthotropic plate is described by the numerical-analytical method of boundary elements. As is known, the basis of this method is the analytical construction of the fundamental system of solutions and Green's functions for the differential equation (or their system) for the problem under consideration. To account for certain boundary conditions, or contact conditions between the individual elements of the system, a small system of linear algebraic equations is compiled, which is then solved numerically. It is shown that four combinations of the roots of the characteristic equation corresponding to the differential equation of the problem are possible, which leads to the need to determine sixty-four analytical expressions of fundamental functions. The matrix of fundamental functions, which is the basis of the transcendental stability equation, is very sparse, which significantly improves the stability of numerical operations and ensures high accuracy of the results. An analysis of the numerical results obtained by the author's method shows very good convergence with the results of finite element analysis. For both variants of the boundary conditions, the discrepancy for the corresponding critical loads is almost the same, and increases slightly with increasing critical load. Moreover, this discrepancy does not exceed one percent. It is noted that under both variants of the boundary conditions, the critical loads calculated by the boundary element method are less than in the finite element calculations. The obtained transcendental stability equation allows to determine critical forces both by the static method and by the dynamic one. From this equation it is possible to obtain a spectrum of critical forces for a fixed number of half-waves in the direction of one of the coordinate axes. The proposed approach allows us to obtain a solution to the stability problem of an orthotropic plate under any homogeneous and inhomogeneous boundary conditions.

1 Introduction

The development level of production at the present stage is characterized by the widespread introduction of new technologies for the manufacture of high-strength materials with orthotropic (orthogonally anisotropic) properties.

Such materials include fiberglass; composite materials reinforced with sequentially alternating layers of fibers in two mutually perpendicular directions; glued wood plates; sheet rolled metals, in which anisotropy begins to appear upon transition to the plastic stage of work, etc.

The widespread use of materials with anisotropic properties has given rise to large-scale studies in the field of mechanics of anisotropic structures and, in the first place, plates.

In many industries, designs in the form of plates made of orthotropic materials with three planes of symmetry of elastic properties are widely used. Under certain conditions, the operation of such plates is accompanied by the appearance of compressive stresses in the median plane, which can lead to a loss of stability and bearing capacity of the plate.

Determining the critical load on a plate presents serious mathematical difficulties not only for orthotropic, but also for isotropic plates. In well-known monographs and reference books, only the stability problem of a rectangular plate with a hinged support along the contour is solved [1-4].

2 Latest researches analysis

The stability problem of an isotropic rectangular plate loaded on two opposite edges by forces distributed according to a linear law was first solved by I. G. Bubnov and S. P. Timoshenko [5]. For an orthotropic plate, this problem was solved by S. G. Lehnitsky [6]. All these classical solutions are obtained for the case of the edges simple support of the plate in the form of double trigonometric rows.

From later works, we note I. E. Harik papers [7, 8], the first of which sets out a numerical-analytical method for the analysis of orthotropic rectangular plates subject to uniform, linearly changing and piecewise-continuous plane loads; the decision procedure is based on the

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classical method of variables separation. And the second one proposes an analytical method for solving the problem of elastic bending of orthotropic rectangular plates under different boundary conditions. A generalization of all the results obtained in this direction was made by F. Bloom and D. Coffin in an interesting Handbook [9], which is, in our opinion, the most comprehensive review of theoretical methods for calculating the stability of thin plates.

There are very few contemporary works devoted to the stability of anisotropic plates. We note the paper [10], where the stability problem of an anisotropic plate is solved (but again with a hinged support along the contour) and the work [11], where the stability problem is solved for pure bending of an orthotropic plate, in which two opposite edges are free and two other edges articulated. The finite difference method was used here. The works of foreign authors are based primarily on the use of numerical methods, and, most often, the finite element method and its modifications are encountered. The paper [12] considers the analysis of vibrations and stability of thick orthotropic plates using finite elements based on the Treffz hybrid formula. The Treffz type finite element method (TFEM) is used by C. Young [13] to solve some potential problems in orthotropic environment. The method of boundary elements in classical form was used in [14]. Here, fundamental solutions are obtained for orthotropic thick plates with allowance for lateral shear strain. Boundary integral equations are formulated that are adapted to arbitrary boundary conditions. Examples of numerical implementation are given.

3 Research aim

The aim of research is an experimental study of the influence of steel fiber on the bearing capacity, deformability and crack resistance of serial reinforced concrete multi-hollow slabs manufactured in the factory.

4 Materials and methods

Problems of this kind can be solved by numerical methods, such as the finite element method, the finite difference method, the R-function method, etc., but it is advisable to verify the results by any analytical method. It seems that such is the NA BEM. As is known [15], the basis of this method is the analytical construction of the fundamental system of solutions and Green's functions for the differential equation (or their system) for the problem under consideration. To account for certain boundary conditions, or contact conditions between the individual elements of the system, a small system of linear algebraic equations is compiled, which is then solved numerically. In this case, no restrictions are imposed either on the boundary conditions or on the nature of the external load. Note that the method is strictly mathematically justified, since it uses fundamental solutions of differential equations, therefore, taking into account the initially accepted hypotheses, it allows to obtain exact values of the desired quantities of the problem.

5 Research results

The differential stability equation of an orthotropic plate within the framework of the Kirchhoff-Love hypothesis (Fig. 1) can be written as

$$D_1\frac{\partial^4 W(x,y)}{\partial x^4}+2D_3\frac{\partial^4 W(x,y)}{\partial x^2\partial y^2}+D_2\frac{\partial^4 W(x,y)}{\partial y^4}+$$
$$+N_x(y)\frac{\partial^2 W(x,y)}{\partial x^2}+2N_{xy}\frac{\partial^2 W(x,y)}{\partial x\partial y}+ \quad (1)$$
$$+N_y(x)\frac{\partial^2 W(x,y)}{\partial y^2}=q(x,y),$$

where stiffnesses are defined by formulas

$$D_1=\frac{E_x h^3}{12(1-\mu_{xy}\mu_{yx})};\quad D_2=\frac{E_y h^3}{12(1-\mu_{xy}\mu_{yx})};$$
$$D_3=D_1\mu_{xy}+2D_k=D_2\mu_{yx}+2D_k;\quad D_k=\frac{Gh^3}{12}.$$

Here E_x, E_y – moduli of elasticity in the axis directions; G – shear modulus; h – plate thickness; μ_{xy}, μ_{yx} – Poisson's ratio; $W(x, y)$ – deflection amplitude value; $N_x(y)$; N_{xy}; $N_y(x)$ – forces in the middle plane; $q(x, y)$ – transverse load amplitude.

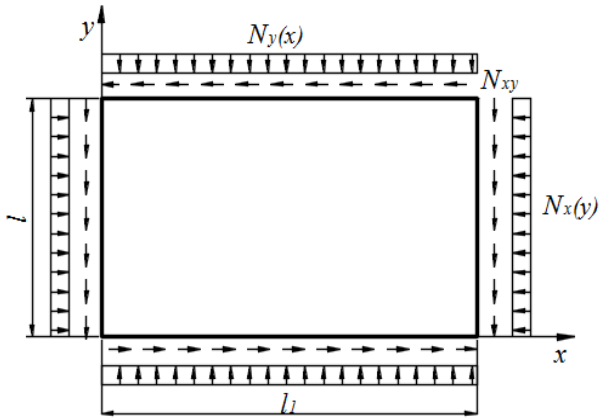


Fig. 1. Plate loads.

The stability equation (1) is of the fourth order and is a partial differential equation. Function $W(x, y)$, which is the solution of this equation, depends on two variables. The transition from a two-dimensional problem to a one-dimensional one, as required by the algorithm of the NA BEM, can be accomplished by applying the Kantorovich-Vlasov variational method.

Let's expand the deflection $W(x, y)$ into functional series:

$$W(x,y)=W_1(y)X_1(x)+W_2(y)X_2(x)+\ldots$$
$$\ldots+W_n(y)X_n(x). \quad (2)$$

Functions $X_i(x)$ it is necessary to choose such that they most accurately describe the shape of the curved

surface of the plate in the direction of the axis ox. Deflection curves for a beam that has the same abutment conditions as the plate in the direction of the axis ox meet his requirement. To select the lateral deflection distribution function $X_i(x)$ there are known two methods – static and dynamic [15]. When using the static method, the deflection of the beam is determined by the static load. This load should be such that symmetric and skew-symmetric forms of the deflection curve alternate alternately. Functions $X_i(x)$ are represented in the form of power polynomials that are easy to differentiate, integrate and calculate without the use of complex programs. When using the dynamic method, beam deflections are represented by forms of its own vibrations. In a static way, you need to build functions $X_i(x)$ depending on the load and reactions of the beam. In the dynamic method, it is enough to change only the values of the natural frequencies, which is very convenient.

We will keep in (2) one member of the series, which, as shown in [15], is sufficient to obtain a result of acceptable accuracy, i.e.

$$W(x, y) = W(y)X(x). \tag{3}$$

Let's substitute (3) into (1):

$$D_1X^{1V}W + 2D_3X''W'' + D_2XW^{1V} + N_x(y)WX'' + \\ +2N_{xy}W'X' + +N_y(x)W''X = q(x, y). \tag{4}$$

Multiply both sides of (4) by X and integrate within [0; l_1], where l_1 – plate dimension in axis x direction (Fig. 1).

$$D_1W\int_0^{l_1} X^{1V}Xdx + 2D_3W''\int_0^{l_1} X''Xdx + D_2W^{1V}\int_0^{l_1} X^2dx + \\ +N_x(y)\int_0^{l_1} X''Xdx + 2W'\int_0^{l_1} N_{xy}X'Xdx + W''\int_0^{l_1} N_y(x)X^2dx = \\ = \int_0^{l_1} q(x, y)Xdx.$$

We introduce the notation:

$$D_2\int_0^{l_1} X^2dx = A;\ \int_0^{l_1}[2D_3X'' + N_y(x)]Xdx = B; \\ \int_0^{l_1} 2N_{xy}X'Xdx = K;\ \int_0^{l_1}[D_1X^{1V} + N_x(y)]Xdx = C,$$

then

$$AW^{1V} + BW'' + KW' + CW = q(y), \tag{5}$$

where

$$q(y) = \int_0^{l_1} q(x, y)Xdx.$$

Coefficients A, B, K, C can be calculated in any mathematical program with almost any accuracy.

From the introduced notation it follows that $N_y(x)$ can be any function of x, while $N_x(y)$ and $N_y(x)$ should be piecewise constant functions of y, since otherwise, equation (5) will be a differential equation with variable coefficients.

Divide all the terms of equation (5) by A:

$$W^{1V} + 2r^2W'' + f^3W' + s^4W = \frac{1}{A}q(y), \tag{6}$$

where

$$r^2 = \frac{B}{2A};\quad f^3 = \frac{K}{A};\quad s^4 = \frac{C}{A}$$

Equation (6) with initial conditions $W(0)$, $\theta(0)$, $M(0)$, $Q(0)$ forms the Cauchy's problem:

$$\begin{vmatrix} W(y) \\ \theta(y) \\ M(y) \\ Q(y) \end{vmatrix} = \begin{vmatrix} A_{11} & A_{12} & -A_{13} & -A_{14} \\ A_{21} & A_{22} & -A_{23} & -A_{13} \\ -A_{31} & -A_{32} & A_{22} & A_{12} \\ -A_{41} & -A_{31} & A_{21} & A_{11} \end{vmatrix} \begin{vmatrix} W(0) \\ \theta(0) \\ M(0) \\ Q(0) \end{vmatrix} + \\ + \int_0^y \begin{vmatrix} A_{14}(y-\xi) \\ A_{13}(y-\xi) \\ -A_{12}(y-\xi) \\ -A_{11}(y-\xi) \end{vmatrix} q(\xi)d\xi.$$

The solution of the Cauchy problem allows us to determine the fundamental functions, the form of which depends on the roots of the characteristic equation

$$t^4 + 2r^2t^2 + f^3t + s^4 = 0 \tag{7}$$

Consider the practically important case when $N_{xy} = 0$. Moreover, in equation (7) will be $f = 0$, and the roots of the characteristic equation are calculated by the formulas

$$t_{1-4} = \pm\sqrt{r^2 \pm \sqrt{r^4 - s^4}}$$

The form of fundamental functions is determined by the relation between r and s, which depends on the fixing conditions of the longitudinal edges of the orthotropic plate. Four options are possible for this ratio:

1. $|s| > |r|$ – complex roots: $t_{1-4} = \pm\alpha \pm i\beta$, where $\alpha = \sqrt{\frac{s^2 - r^2}{2}}$; $\beta = \sqrt{\frac{s^2 + r^2}{2}}$.

2. $s^4 < 0, r^2 \neq 0$ – real and imaginary roots: $t_{1-2} = \pm\alpha; t_{3-4} = \pm i\beta$.

3. $s^4 > 0, |s| < |r|, r^2 > 0$ – imaginary roots: $t_{1-2} = \pm i\alpha; t_{3-4} = \pm i\beta$.

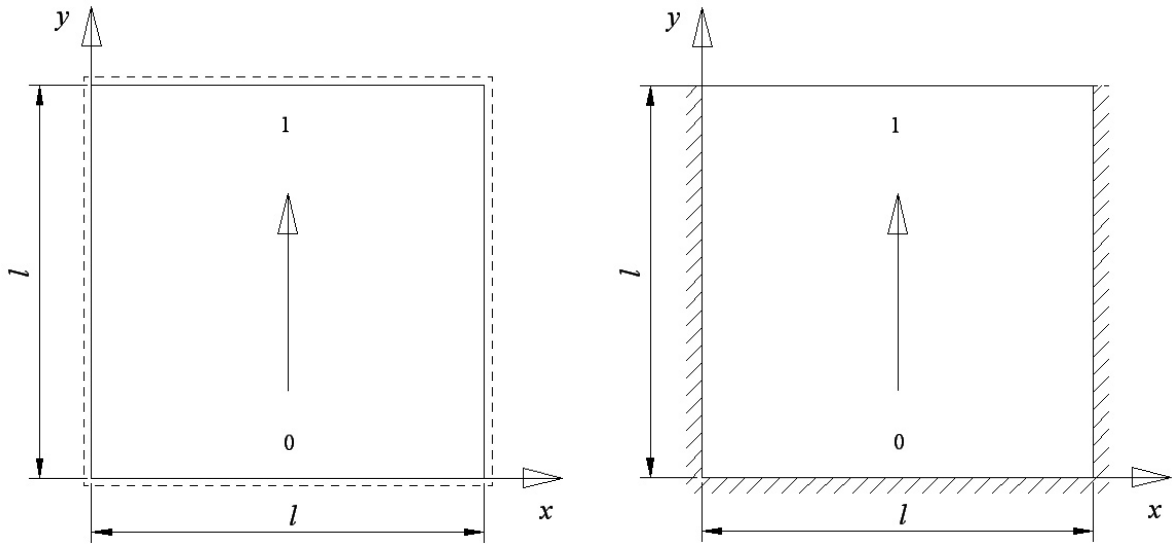
4. $s^4 > 0, r^4 - s^4 > 0, r^2 < 0$ – real and different roots: $t_{1-2} = \pm\alpha; t_{3-4} = \pm\beta$.

After determining the fundamental functions, one can compose a transcendental equation of stability of an

orthotropic plate, which in the general case will have the form

$$\left|A_*(N_x, N_y, N_{xy}) = 0\right| \quad (8)$$

where A_* – a square matrix of values of fundamental orthonormal functions with compensating elements describing the topology of the system.



Option 1 Option 2

Fig. 2. Two options of boundary conditions.

Initial data for calculation:

Elasticity moduli – $E_x = 5 \cdot 10^3$ MPa, $E_y = 200 \cdot 10^3$ MPa, $E_x = 5 \cdot 10^3$ MPa; shear moduli – $G_{xy} = 12{,}5 \cdot 10^3$ MPa, $G_{yx} = 25 \cdot 10^3$ MPa, $G_{xz} = 50 \cdot 10^3$ MPa; Poisson's ratios – $\mu_{xz} = 0{,}1$, $\mu_{yz} = 0{,}15$, $\mu_{xy} = 0{,}0075$.

The numerical implementation of the NA BEM algorithm is performed in the Excel. The results are shown in table 1.

Table 1. Critical loads, calculated by two methods.

Load,	Option 1			Option 2		
kN/m	BEM	ANSYS	%	BEM	ANSYS	%
σ_1	11395	11436	0,36	12320	12372	0,42
σ_2	11758	11808	0,42	35953	36101	0,41
σ_3	14989	14958	0,46	41669	41872	0,48
σ_4	19800	19902	0,51	70552	70855	0,43
σ_5	20002	20133	0,65	80201	80662	0,57

To assess the accuracy of the results, the plate was modeled in ANSYS [16]. The calculation of plates by the finite element method under two variants of the boundary conditions showed good convergence of the results obtained by the two methods (Table 1). The first three forms of buckling are given in table 2.

6 Conclusions

Thus, the stability problem for an orthotropic rectangular plate leads to four possible combinations of the roots of the characteristic equation of the problem, and, therefore, the complete solution of the problem will be determined by 64 analytical expressions of fundamental functions.

The roots of equation (8) form the spectrum of critical forces of the plate in question.

Let's look at some examples. We will determine the first three critical loads and three forms of buckling of a plate made of orthotropic material under two boundary conditions: hinged support along the entire contour (option 1) and rigid fixing of the plate on three sides with a free fourth side (option 2) (Fig. 2).

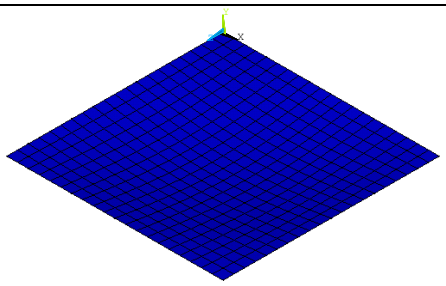
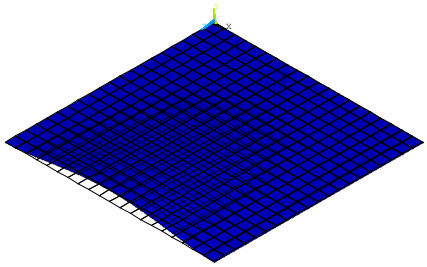
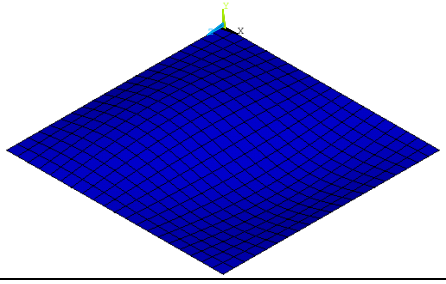
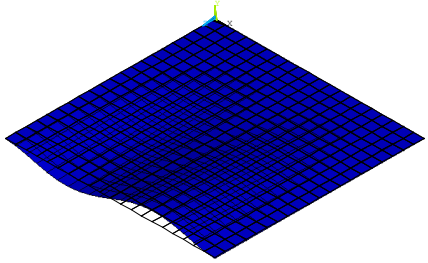
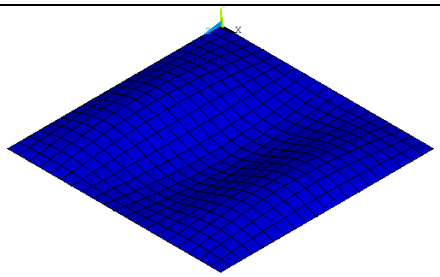
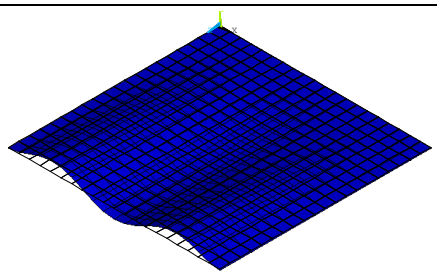
The matrix of fundamental functions, which is the basis of the transcendental stability equation, is very sparse, which significantly improves the stability of numerical operations and ensures high accuracy of the results.

An analysis of the numerical results obtained by the author's method shows very good convergence with the results of finite element analysis. For both variants of the boundary conditions, the discrepancy for the corresponding critical loads is almost the same, and increases slightly with increasing critical load.
Moreover, this discrepancy does not exceed one percent. It should be noted that for both variants of the boundary conditions, the critical loads calculated by the boundary element method are less than in the finite element calculations.

The obtained transcendental stability equation allows one to determine critical forces both by the static method and by the dynamic one. From this equation it is possible to obtain a spectrum of critical forces for a fixed number of half-waves in the direction of one of the coordinate axes. For example, one half-wave in the direction of the axis *Ox* and many half-waves in the direction of the axis *Oy* (Fig. 1), two half-waves in the direction of the axis *Ox* and many half-waves in the direction of the axis *Oy* etc., depending on the magnitude of the coefficients *A*, *B*, *K*, *C*.

The proposed approach allows us to obtain a solution to the stability problem of an orthotropic plate under any homogeneous and inhomogeneous boundary conditions.

Table 2. Buckling forms

Option 1	Option 2
First form	
	
Second form	
	
Third form	
	

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Selection of effective corrosion inhibitors for bischofite solutions and simulated medium of formation waters

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Abstract. Questions of the corrosion inhibitors selection for protection of oil-field pipelines have been studied in the article. Results of research of technological and anticorrosive properties of the corrosion inhibitors in mediums simulating industrial environments are presented. The methodological approaches to selection of the corrosion inhibitors on a stage of laboratory experiments on an example of Kaverdinsky gas-condensate deposites have been described. It was found that all the surfactants tested in the simulated medium of the formation waters show a protective effect of more than 90% with a dosage of 1 g/dm^3. It is recommended to use bischofite solution with a mass fraction of 24% $MgCl_2$ and corrosion inhibiting 0.1% KI-1M admixture to protect industrial gas pipelines from carbon dioxide corrosion. This composition provides a degree of corrosion protection to 99.6%. The results of industrial tests confirmed the effectiveness of complex system – bischofite solution with a mass fraction of 24 % $MgCl_2$ and addition of 0.1% KI-1M corrosion inhibitor. The cationic surfactants KI-1M, St, SRK and amphoteric surfactants EM and KAPB effectively protect in simulating medium and provide a degree of protection from carbon dioxide corrosion to 91.2-98.9%.

Introduction

Corrosion is one of the main causes of equipment durability in the oil and gas industry, which causes huge economic losses and environmental damage [1-7]. Despite the progress made in combating corrosion destruction of gas equipment, more than 3000 failures of hydrocarbon collection systems pipelines because of internal corrosion are recorded annually.

Repair works of these breakages dramatically increases the cost of operating wells and hydrocarbon collection systems. Neglect of corrosion protection leads to frequent interruptions of work, and in some cases, at break of oil-well tubing to stoppage of hydrocarbon production. The main indirect losses from corrosion are underproduction due to emergency and repair stops, ecological sanctions.

The introduction of advanced technologies for the protection of operational equipment contributes to the reduction of labor and material costs, reducing the duration and cost of repair and rehabilitation works carried out at industrial enterprises [6]. These measures will ensure sustainable future development in the operation of oil and gas fields under conditions of carbon dioxide corrosion.

Important factors affecting degree and nature of corrosion damage are: 1) speed of gas-liquid flow; 2) tensile stresses of tubing; 3) volume ratio of water to hydrocarbon condensates in a liquid phase of flow; 4) inflow into the well of formation waters of different salt composition; 5) influence of organic water-soluble acids [1, 6, 7].

The mechanism of carbon dioxide corrosion has been studied quite deeply and comprehensively [1, 8-11]. The intensity of corrosive destruction of equipment at CO_2 containing deposits is determined by partial pressure of carbon dioxide (at a low content of organic acids) and the temperature at which corrosion process takes place [1, 2, 4].

During the movement of gas through a wellbore, a liquid phase is released, resulting in a three-phase gas flow of gas-water-hydrocarbon inside the pipes. The intensity of corrosion in a three-phase system is mainly due to the structure and flow regime. Corrosive activity of medium in a well depends on ratio of hydrocarbons to water. According to some researchers, intensive corrosion of equipment begins with content of 0.1% of water in a well, then the corrosion rate remains constant, although the water content increases.

Key directions for improving corrosion control are use of: 1) inhibitors; 2) new designs and methods of application of insulating coatings; 3) various technological measures; 4) high-efficiency and economical pipes; 5) reliable and timely methods of inspection of existing pipelines without disturbing their mode of operation [1, 12].

One of the important methods to reduce corrosion of oil and gas equipment is to use of steel alloys and non-ferrous alloys, but their high cost limits widespread use of this highly effective method of corrosion control [1].

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Application of protective coatings in the fight against corrosion is also not widely used in practice. Metal coatings do not have sufficient protective properties under acid treatments at high temperatures, and are particularly sensitive to voltage concentrators. Non-metallic coatings are not capable to provide the required pipe surface insulation against corrosive agents and are merely a substrate for a thicker coating film of glass, enamel or polymer [12].

Inhibitory protection is environmentally sustainable in the future and one of the simplest, most effective and in many cases economically feasible methods of corrosion control [13-16]. Its undoubted advantage is the possibility of application without change of the corresponding technological processes and hardware design on already existing industrial projects. Other protection measures usually require replacement of existing equipment with new ones, which entails significant capital expenditures.

Therefore, it is advisable to consider the problem of selecting corrosion inhibitors to reduce the corrosive effect on gas equipment and the importance of laboratory research in solving this problem.

Problem statement

The results of laboratory tests are an important and objective measure of the rate of corrosive hazardous fluids action and are the basis for planning, analyzing, conducting and evaluating the results of anti-corrosion measures (in particular, the use of corrosion inhibitors). The higher the level of laboratory research used to select a corrosion inhibitor, the more reasonable are conclusions as to expediency of its use and, as a consequence, more targeted corrosion measures will be planned.

A distinctive feature of industrial piping systems is branching, presence of different diameters sections, a considerable number of local hydraulic resistances (latches, elbows, inserts, compensators, etc.). In addition, industrial pipelines are characterized by a continuous change in costs, phase and chemical composition of the transported products. The consequence of this is the instability and unpredictability of corrosive aggressiveness of the environment, localization of corrosion damage both along the route and along the intersection of pipes [14, 15]. All this causes the complexity of inhibitors choice problem and the technology of their application, the need for constant monitoring of effectiveness and sets up special demands to corrosion inhibitors themselves.

Corrosion inhibitors for industrial piping systems should be characterized by:

1) high protective properties in environments with constantly variable (sometimes in a wide range) chemical composition and hydrodynamic flow characteristics;
2) implementability – the possibility to use in existing technological schemes; stability of properties in processes of storage and use, taking into account climatic characteristics of a region;
3) cost-effectiveness – reagents should have an optimal price / quality ratio, taking into account the risks of operating specific industrial pipelines;
4) indifference – they should not have a negative impact on processes of transportation and processing of hydrocarbon products.

Almost all commercially manufactured corrosion inhibitors have their own sphere of application. This sphere is limited by technological features of equipment which is protected and by composition of corrosive active mediums.

The available range of modern corrosion inhibitors for oil and gas industry determines need for sound technological and economic choice of reagents, taking into account the operation peculiarities of various types of industrial pipelines. Laboratory researches play an important role in this selection. During laboratory process the following tasks are solved:

- simulation of corrosion processes in a real pipeline;
- detection of corrosion mechanism of steel grades of pipe;
- testing of inhibitor – selection of the most effective reagents for specific objects, specification of technology of their application;
- the identification of optimal application areas for specific inhibitor.

Therefore, selection of inhibitors for a specific oil and gas industry pipeline, or system of pipelines includes such stages:

1) analysis of technological characteristics of sites or system of industrial pipelines;
2) advance determination of reagents range, which suit to these conditions;
3) analysis of technological and anticorrosive features of inhibitors in laboratory conditions to detect the most effective ones;
4) bench and pilot tests of selected inhibitors.

The adoption of feasible practices of laboratory tests procedure for cleaning pipelines is shown schematically in Fig. 1 [9, 14, 15].

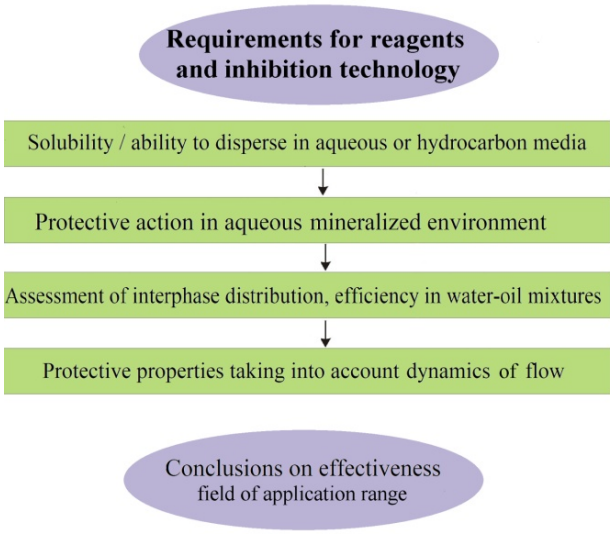

Fig. 1. Laboratory tests procedure for selection of corrosion inhibitors for gas pipelines.

Materials and methods

Brief characteristics and features of the methodology for conducting experiments on the selection of corrosion inhibitors in laboratory conditions are presented below. Work results carried out on the selection of corrosion inhibitors for the conditions of industrial pipelines of the Kaverdinsky gas condensate deposites, where the problem of carbon dioxide corrosion is acute, are submitted as an example. In addition, wells operation and industrial equipment are complicated by intensive hydrate formation. Corrosive activity of the transported medium by industrial pipelines is significant due to the high mineralization of water as a result of the use of bischofite solutions as hydrate formation inhibitor and the content of aggressive components CO_2 (up to 5.3%).

In laboratory conditions, studies were conducted on the selection of a corrosion inhibitor for conditions when bischofite is used as a hydrate formation inhibitor.

Bischofite solution has better antihydrate activity than calcium chloride, and no worse than methanol [17]. Currently, significant reserves of anhydrous magnesium chloride have been discovered in the Dnieper-Donets Rift; within borders of the Orchikivsk Depression, the estimated resources are about 10 billion tons. Commercially it is produced by washing mineral deposits of bischofite through a well. The cost of bischofite is much lower than methanol and calcium chloride. Bischofite is a nonvolatile, ecologically sustainable reagent [113].

Bischofite solution with a mass fraction of 24% $MgCl_2$ + 3 g/dm^3 CH_3COOH was used to study effectiveness of the corrosion inhibitors. Concentration of acetic acid was chosen because of the maximum content of low molecular weight carboxylic acids in the formation waters of wells of Northeastern Ukraine. Lighted condensate was used as hydrocarbon phase, as it has neutral reaction of medium and constant fractional composition and as gaseous medium, carbon dioxide or oxygen.

Solubility of the reagents in the simulated medium was visually evaluated. Ability of reagents to form real or colloidal solutions and their stability were evaluated. As a result, 16 cationic and amphoteric surface-active substances were selected from more than one hundred surface-active substances that are highly soluble in aqueous solution. This indicates that the use of all reagents is possible in industrial gas pipelines transporting waterlogged products due to their high protective properties.

Thus, surfactants requirements were: 1) chemical structure of surfactants based on fundamental theoretical concepts; 2) coagulative stability in bischofite solution; 3) slight foaming; 4) protective anticorrosive action in hydrous mineralized waters; 5) thermal stability; 6) non-toxicity and safety for personnel and environment; 7) economic efficiency during industrial use.

The next stage is selection of reagents for protective properties based on evaluation of inhibitors protective effect in aqueous mineralized media ("bubble test"), rejection of ineffective ones, determination of applications spheres with respect to composition of aqueous medium and preliminary determination of working dosages.

Research and evaluation of the protective effect of inhibitors was carried out in accordance with GOST 9.905-82 "Methods of corrosion tests. General requirements", GOST 9.502-82 "Metal corrosion inhibitors for water systems. Methods of corrosion tests", GOST 9.506-87 "Inhibitors of metal corrosion in water-oil environments".

Corrosive aggressiveness of the medium was evaluated by gravimetric method, according to loss of samples mass. Control experiment was without addition of reagents.

Corrosion tests were carried out on steel P-110 (table 1). This type of steel is widely used for tubing.

Table 1. Chemical composition of steel P 110.

C	Si	Mn	P	S	Cr	Ni	Cu
0.26-0.395	0.17-0.37	–	≤ 0.02	≤ 0.01	0.80-1.10	≤ 0.20	≤ 0.20

Corrosion studies were carried out in a thermostatic installation (Fig. 2.) The installation is designed at the All-Union Scientific Research Institute of Natural Gases and Gas Technologies (VNIIGAZ) for determination of corrosion rate in the simulated conditions of industrial pipelines [18]. It is a glass vessel in which the test solution was poured and a fluoroplastic cylinder with witness samples and a propeller stirrer was placed.

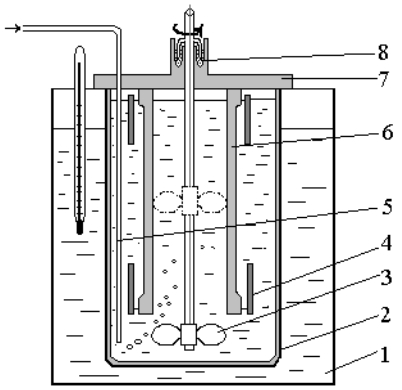

Fig. 2. Installation diagram for corrosion research:
1 – thermostat; 2 – glass chamber; 3 – mixer; 4 – metal piece;
5 – gas supply tube; 6 – fluoroplastic cylinder; 7 – cap;
8 – hydraulic seal.

The cell was attached to an electric motor that rotated the stirrer. During rotation of the stirrer, circular fluid motions in the laminar mode were created in the fluoroplast cylinder with a flow rate of 0.3-0.5 m/s. When the propeller was mounted below the bottom of the cylinder, it was rotated at a speed of 1400 revolutions per second. There was a circular motion of the fluid in turbulent mode. The speed of stream flow in the area of placement of metal piece was 7-8 m/s. In addition to circular motion, fluid was also circulated through the small cylinder by creating irritation during rotation of the stirrer.

The corrosion rate of the metal was calculated by the formula [18, 19, 20]:

$$v = \frac{\Delta m}{S\tau} \quad (1)$$

where v – the corrosion rate g/(m² h);
Δm – the loss of the metal piece, g;
S – the surface area of the coupon, m²;
τ – the test duration, h.

Protective effect of test reagents in bischofite solution (Z) was calculated by the formula [18, 19]:

$$Z = \frac{v_0 - v_1}{v_0} 100 \quad (2)$$

where, v_0 – corrosion rate of the metal piece without the corrosion inhibitor e, g/(m²·h);
v_1 – corrosion rate of the metal piece with the corrosion inhibitor e, g/(m²·h).

Average permeability is calculated according to the mass loss [20]:

$$P = 8.76 \cdot v/\gamma \quad (3)$$

where P – permeability, mm/year;
8.76 – the conversion coefficient;
v – the corrosion rate, g/(m² /h);
γ – metal density, g/cm³.

Quantitative indicators of the experiments were analyzed by methods of mathematical statistics with the calculation of average sample values, variance and errors of average values in groups of indicators. The significance of differences in the results obtained for different groups was determined by Student's t-test. Differences were considered statistically proven with a generally accepted probability of error $p < 0.05$.

Based on the results of preliminary studies, the following reagents were selected for further experiments: corrosion inhibitor KI-1M, cationic surfactants Stentex (St), Sulforocanol (SRK), amphoteric surfactants Emily (EM) and Cocamidpropylbetaine (KAPB):

KI-1M – acid corrosion inhibitor, cationic surfactant, a mixture of catapine and urotropine;

Stentex (St) – cationic surfactant, quaternary ammonium compound;

Sulforocanol (SRK) – cationic surfactant with the general formula R – O – $(C_2H_4O)_2$ – SO_3, where R = $C_nH_{2n\div1}$; n = 12÷14 and a molecular weight of about 388.

Emily (EM) – amphoteric surfactant, the mixture of sodium and magnesium salts of lauryl and oleyl alcohols estersulfates;

Cocamidpropylbetaine (KAPB) – amphoteric surfactant, the fatty acid amide derivative with betaine structure.

In order to identify the possibility of combined application of a hydrate inhibitor, bischofite which is used in the deposits, and corrosion inhibitors under study, protective properties of inhibitors in bischofite solutions with concentration of 24% of $MgCl_2$ were determined.

Research results

The obtained dependences of corrosion rate on concentration which are shown in Fig. 3, 4, allowed to isolate the minimum required concentration of reagents, for the test reagents – 1-2 mg/dm³.

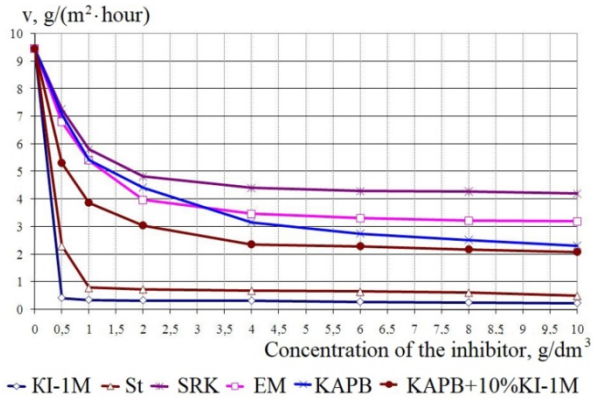

Fig. 3. Dependence of the corrosion rate of steel on the concentration of surfactants in bischofite solution in carbon dioxide environment (w_{MgCl_2} = 24%, T = 80 °C, 3 g/dm³ CH_3COOH, t = 2 h, volume fraction of condensate 25%, P_{CO_2} = 0.1 MPa.).

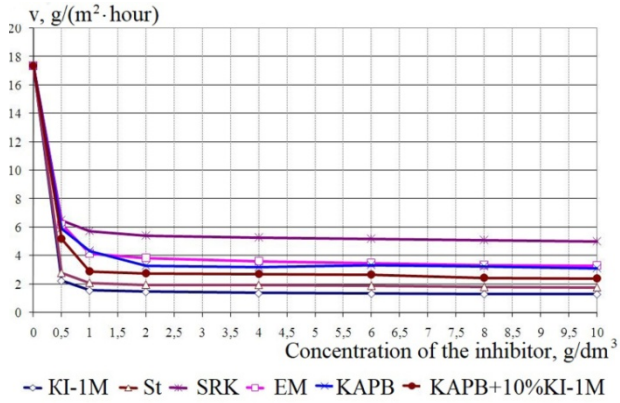

Fig. 4. Dependence of the corrosion rate of steel on the concentration of surfactants in bischofite solution in an oxygen environment (w_{MgCl_2} = 24%, T = 80 °C, 3 g/dm³ CH_3COOH, t = 2 h, volume fraction of condensate 25%, P_{O_2} = 0.1 MPa.).

The highest inhibitory effect in bischofite systems – low molecular weight carboxylic acids – carbon dioxide/oxygen at the content of reagents in a solution of 1 g/dm³ revealed surfactants KI-1M, St, respectively, 83.5-96.2% and 77.8-91.5 % (Fig. 5). The remaining reagents have a lower degree of protection at the appropriate concentration.

Due to mathematical data processing, polynomial and power mathematical models were selected. In an environment with O_2, polynomial equations (Equations 4) give a low level of reliability of parameters, the obtained reliability indicators for the coefficients significantly exceed the level of 0.05

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 \quad (4)$$

where, y – corrosion rate, g/(m²·h);
x – concentration of inhibitor, g/dm³;
a_0, a_1, a_2, a_3 – empirical coefficients.

In CO_2 environment, polynomial model in three cases out of six describes the experimental data as well

as the power data (in the presence of SRK, EM, KAPB).

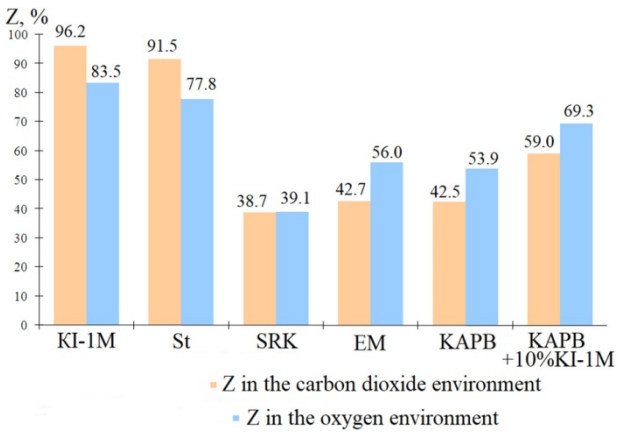

Fig. 5. Protective effect of test reagents in bischofite solution (w_{MgCl_2}= 24%, T = 80 °C, 3 g/dm^3 CH_3COOH, t = 2 h, concentration of surfactants 1 g/dm^3, volume fraction of condensate 25%, P_{CO_2/O_2} = 0.1 MPa).

It should be noted that, in addition to the correlation coefficient, an important indicator of the adequacy of the approximation model is a residual error. The smaller the residual error value, the more accurate the model describes the experimental data. In all cases, residual error when using the power function (Equation 5) is significantly smaller than when using the polynomial, which indicates a much higher quality of approximation. For all inhibitors, the coefficients of the equation are reliably determined by $p < 0.05$

$$y = b_0 + (b_1 x + b_2)^{-3} \quad (5)$$

where, y – corrosion rate, g/(m^2·h);
x – concentration of inhibitor, g/dm^3;
b_0, b_1, b_2 – empirical coefficients.

The coefficients and parameter estimates of nonlinear approximation equation are shown in Table 2, $p < 0.05$.

Table 2. Coefficients and parameter of nonlinear approximation equation 5.

Surfactant	Equation coefficients			Estimation of the approximation equation parameters		
	b_0	b_1	b_2	R	R^2	Residual error
For the O_2 environment						
KI-1M	1.35	1.28	0.34	0.999	0.9997	0.01
St	1.85	1.24	0.40	0.999	0.9999	0.02
SRK	5.21	0.93	0.43	0.999	0.9992	0.11
EM	3.41	0.60	0.42	0.999	0.9992	0.13
KAPB	3.21	0.60	0.41	0.999	0.9995	0.09
KAPB+ KI-1M	2.49	0.65	0.41	0.999	0.9985	0.28
For the CO_2 environment						
KI-1M	0.28	2.85	0.48	0.999	0.9999	0.01
St	0.57	0.74	0.48	0.999	0.9978	0.15
SRK	4.16	0.26	0.57	0.999	0.9971	0.07
EM	3.14	0.24	0.54	0.999	0.9977	0.08
KAPB	2.35	0.15	0.52	0.998	0.9965	0.16
KAPB+ KI-1M	2.20	0.32	0.52	0.999	0.9984	0.07

Produced formation water is corrosive-aggressive phase of extracting fluid. So the efficiency of complex systems (bischofite 24% $MgCl_2$ + surfactants 0.1%) in relation to simulated medium of formation water is determined. The obtained data show (Fig. 6) that bischofite solution inhibits the process of carbon dioxide corrosion. All complex systems under study provide a degree of metal protection over 90 °C.

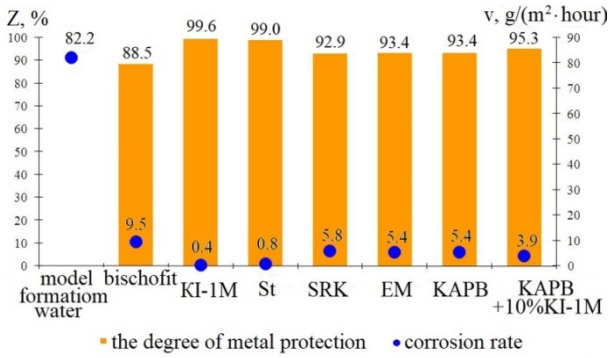

Fig. 6. Protective action of bischofite-based complex inhibitors against the reservoir model environment water (w_{MgCl_2}= 24%, T = 80 °C, 3 g/dm^3 CH_3COOH, t = 2 h, concentration of surfactants 1 g/dm^3, volume fraction of condensate 25%, P_{CO_2}= 0.1 MPa).

Comparative analysis of the data indicates the feasibility of using bischofite solution with a mass fraction of 24% of $MgCl_2$ and the addition of a corrosion inhibitor 0.1% KI-1M for protection of industrial gas pipelines from carbon dioxide corrosion, as long as this system provides a degree of protection against corrosion 99.6% relatively to stimulated medium of formation waters.

The results of industrial tests at the Kaverdinsky gas condensate deposits confirmed the efficiency of the complex system (bischofite solution with a mass fraction of 24% of $MgCl_2$ and the addition of a corrosion inhibitor 0.1% KI-1M). Rate of uniform corrosion with constant circulation of the inhibitor in the system did not exceed 0.01 mm/year.

The influence of the reagents on the corrosion rate and their protective effect in the simulated medium of formation waters was investigated. All tested surfactants in the simulated of formation water show a protective effect of more than 90% with a dosage of 1 g/dm^3 (Fig. 7), which satisfies the requirements of regulatory documents for corrosion inhibitors and allows them to be recommended for application at gas-fired facilities.

The protective properties of surfactants in the bischofite environment are 1.0-2.5 times less effective (Fig. 7). The protective effect of surfactants: SRK, EM and CAPB is especially noticeably reduced by 2.2-2.5 times. The KI-1M reagent in bischofite solutions practically does not change its effectiveness (increases by 1.1 times). A degree of protection of more than 90% was detected in the presence of surfactants St and KI-1M. In this regard, the use of SRK, EM and CAPB is appropriate for industrial gas pipelines that transport products with is low-mineralized aquatic environment.

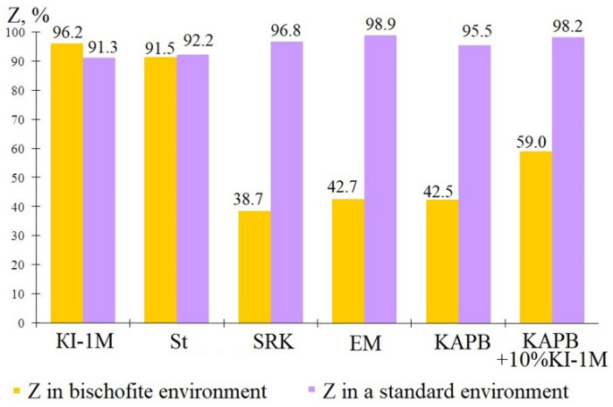

Fig. 7. The degree of corrosion protection in bischofite solutions and simulated environment of formation water with a mass fraction of surfactants 0,1% (the inhibitor concentration is 1 g/dm^3, T=80 °C, 3 g/dm^3 CH_3COOH, t=2 h, concentration of surfactants 1 g/dm^3, volume fraction of condensate 25%, P_{CO_2}= 0.1 MPa).

The obtained values of corrosion rate can be explained by the fact that the surfactants SRK, EM, and KAPB are capable of complexing with metals and are partially spent on the formation of complex compounds with magnesium and calcium ions which are in bischofite solution (Equations 6)

$$Me + JR \leftrightarrow MeRJ \qquad (6)$$

where, *Me* – the solvated metal ion;

J – an inorganic surfactant ion;

R – the hydrocarbon ion of the surfactant.

Nitrogen-containing surfactants KI-1M and St form a hydrophobic film on the surface of metal. This film is a barrier that shields the metal-corrosive environment. In most cases, surfactants are less polar than the components of the bulk phase, or have a low-polar radical. When adsorbed, surfactants replace polar surface with a less polar layer, equalizing polarity difference [15].

The effectiveness of complex inhibitors with respect to simulating environment of formation water in Northeastern Ukraine is represented in Figure 7. Data show that the corrosion rate in the bischofite solution is less than in the simulated medium of formation waters. The corrosion rate in the simulated medium of formation waters is 82.2 g/(m^2·h), and in bischofite solution – 9.5 g/(m^2·h) (Fig. 6) [19]. Such results are explained by the different concentrations of salts in the compared media and the different properties of the two salts ($MgCl_2$ and NaCl) in the high humidity environment. NaCl is more corrosive under immersion environment [21].

All investigated complex systems provide a degree of metal protection of more than 90 °C.

Thus, laboratory experiments to investigate the technological and corrosion properties of corrosion inhibitors are an important step in the selection of corrosion inhibitors for specific pipeline systems and sections. Despite the difficulty of accurately reproducing the technological conditions of corrosion of gas pipelines at the stage of laboratory experiments in condition of a competent methodological approach to the experiments, it is possible to identify reagents that meet the requirements for their protective and technological properties to protect a specific gas industry.

It should be noted that laboratory testing is only the first step in the selection of an inhibitor – it allows to screen out the ineffective and to select the best ones for the next bench and industrial research. Laboratory testing is carried out under more severe conditions than actual tests (overestimated concentrations of CO_2 and O_2, short exposure time of the metal piece), so that the degree of protection is reduced compared to the real one.

Industrial tests of complex inhibitors proposed by the author for improvement of gas wells reliability under conditions of hydration and corrosion, were conducted at the Kaverdinsky gas condensate deposits of CJSC "Plast" for 30 days. The effectiveness of the complex inhibitor in preventing hydration was determined by monitoring the operation of well № 2 in hydration mode without supplying the inhibitor. The dew point of gas was determined by "Kharkov-2M" hydrometer, and the corrosion intensity was based on the testimonials that were installed in the samplers at the wellhead. Corrosion rate at constant circulation of the inhibitor in the system did not exceed 0.01 mm/year.

Conclusions

1. The basis of a complex inhibitor of hydrate formation and corrosion can be ecological sustainable bischofite solutions with the addition of amphoteric and cationic surfactants.
2. In order to reduce the corrosion effect of concentrated bischofite solution on the gas equipment of the Kaverdinsky gas condensate deposits, KI-1M and St inhibitors were selected, the inhibition efficiency of which in carbon dioxide and oxygen environment is 83.5-96.2% and 77.8-91.5 % respectively. The results of industrial tests confirmed the effectiveness of the complex system – bischofite solution with a mass fraction of $MgCl_2$ 24% and the addition of a corrosion inhibitor KI-1M 0.1%). The rate of uniform corrosion at constant circulation of the KI-1M inhibitor in pipelines did not exceed 0.01 mm/year.
3. The cationic surfactants KI-1M, St, SRK and amphoteric surfactants EM and KAPB effectively protect in a reservoir modeling environment and provide a degree of protection from carbon dioxide corrosion of 91.2-98.9%.

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Diagnostics and regulation of rheological characteristics for injection mortars by electromechanical sensors

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Abstract. In the article the diagnostic and regulation problems are considered for the rheological characteristics of mortars which are used for pumping into the interpipe gaps or cracks during repairing the pipelines, tunnels, and other objects. It is important to obtain the necessary mortar viscosity which allows providing a complete hole filling. For this aim the experimental dependencies have been determined between the injection mortar viscosity, the water-cement ratio, and the additives quantity in the mortars. According to the Poiseuille's flow law the theoretical dependencies have been obtained between the penetration depth of the injection mortar and viscosity under the different water-cement ratios. The said dependencies are a base during the development of the functioning algorithm the diagnostic and regulation system of the injection cement mortars rheological characteristics. The description of this functioning system is given. The mentioned system application allows increasing the cementation quality, corrosion resistance and durability of the repaired pipeline sections as well as decreasing of the work duration and labor costs.

1 Introduction

The injection technologies are widely spread for building and repairing of the infrastructure objects. These technologies include mortar injection – cementic, silicate, polymeric – into cracks, pores, seams, holes in building constructions, soil massives and/or between them. For example, the creation of a damp-proof layer against capillary rise by injection of chemical products is one of the most diffused methods, thanks to the relatively easy and cheap application [1]. In this case the hinder is overcoming capillary pressure in fine capillary pores. It requires an increase of the pumping pressure or the viscosity control.

The concrete permeability is becoming a serious problem for durability of hydraulic, water retaining and tunnel constructions due to the water influence or wet medium effect. To prolong service time and defence concrete and reinforced concrete constructions the various kinds of waterproofing are used: monolayer and multilayer ones, for cold and heated surfaces, with filler and without, as membrane or plaster. For each particular case it is necessary to come to a decision about the most effective method for the construction protection [2, 3]. The fiberglass plastics, which are wrapped around pipes, give them greater strength and corrosion resistance [4]. One of the most effective repair methods of sewage pipelines damaged by microbiological corrosion is polymer covering or laminate [5, 6]. The other way is a setting inside the pipeline a corrosion-resistant polymer inserts or steel sleeves [7, 8, 9, 10, 11]. These inserts are placed in the damaged part of the sewage pipeline. A formed intertube gap is filled by polymer or cement mortar which quality defines reliability and durability of the restored sector (Fig. 1). The mortar injection is realized under pressure which is produced by piston or pneumatic mortar pumps *4* through special injector-packers *8*. The mortar is transported from pumps by hoses-mortartransporters.

The movement depth of the mortar by the hoses into crack, interpipe gap, and etc. as well as the cementation quality (filling gap continuity, density, strength, water impermeability of hardened mortar) are determined by mortar rheological parameters – shear yield stress and dynamic viscosity. These characteristics most depend on the water quantity in the mortar, the type and quantity of plasticizing additives – anion-active surfactants. That is why during the injection process it is necessary to carry out ongoing diagnostics of mortar rheological properties. If necessary the rheological properties should be corrected by the change of the water quantity and/or plasticizing additives. The mentioned diagnostics and correction are very difficult for automation, and a specialist usually performs them (Fig. 1, *a*). Nowadays this system should be automatized and computerized (Fig. 2). The development of such systems is an actual task.

The investigation aim is justification and development of the automatic system for diagnostics and correction of cement injection mortar rheological properties.

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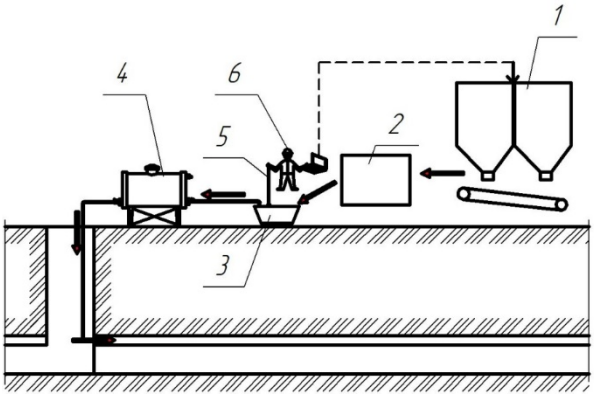
a)



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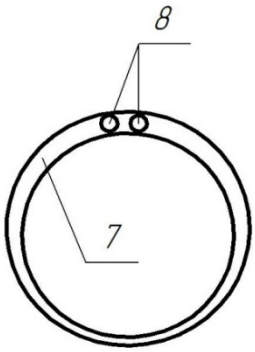
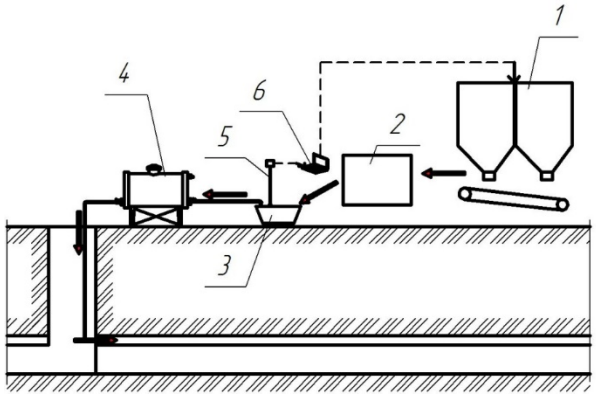


← mortar movement; ----- control signals; *1* – material containers and dispensers; *2* – mortar mixer; *3* – mortar container; *4* – mortar pump; *5* – device for rheological characteristic diagnostics; *6* – specialist; *7* – interpipe gap; *8* – injector-packers

Fig. 1. The cement mortar injection into the interpipe gap during the pipeline repairing by the insert method: *a* – the technological injection scheme; *b* – the injector setting scheme in the interpipe gap abut.



← mortar movement; ----- control signals; *1* – material containers and dispensers; *2* – mortar mixer; *3* – mortar container; *4* – mortar pump; *5* – automatic device for rheological characteristic diagnostics; *6* – system server for diagnostics and regulation of rheological characteristics

Fig. 2. The automatized system for diagnostics and regulation of rheological characteristics.

The research tasks are:

- choice and rationale of the method which is applicable to automatic system for diagnostics of injection mortar rheological properties;
- finding out the dependences applicable to automatic system between the permeation depth and the mortar viscosity needed for penetration ensuring into the whole interpipe gap;
- finding out the dependences applicable to automatic system between the water-cement ratio and the mortar viscosity with and without additive-superplasticizer;
- developing of the automatic system algorithm for diagnostics and regulation of cement injection mortar rheological properties.

2 The choice of the diagnostic method for injection mortars rheological properties

The choice has been carried out based on the analysis of the exist systems for automatic diagnostics and regulation of building materials technological parameters, in particular viscosity. Many researchers consider that rheological approach is more accurate and reliable compared with the traditional tests. Therefore, it is increasingly used in the different technological processes related to mixtures pumping. The studies on concrete pumpability combining different laboratory tools and linkage to rheology are conducted in [12, 13]. The correlation between the rheological properties and the concrete pumpability are analyzed under various temperatures and time after mixing. As the pumpability characteristics the Bingham parameters and slippage resistance are chosen. The predictive capacity of the tribometer concerning the concrete pumpability is validated by measuring the discharge pressure. Also, it has been demonstrated that knowledge of the rheological properties of the lubrication layer is not sufficient to state whether the concrete is pumpable or not. Only a combination of rheological instruments makes the adequate description of concrete pumpability possible.

The yield stress and plastic viscosity values are necessary to ensure adequate filling ability and concrete stability for successful casting of prestressed elements. According to the results [14], it is recommended the concrete to have plastic viscosity within 30-130 Pa·s to provide its proper workability. Higher viscosity levels should be avoided due to its limitation in passing ability. Understanding of the rheological parameters is important for developing the quality control test methods. As it is shown in [15], the concrete rheology affects the surface quality. It is found out that the concrete mixtures with the yield stress lower than 25 Pa provide the best surface quality.

The science of rheology is increasingly used to describe the properties of fresh cement paste. Compared to standard workability tests, rheological properties allow carrying out more fundamental investigation, more precise phenomenological description of flow properties and serving as input for numerical simulations [16]. However, when the cement researchers use rheometers the results depend very much on choice of protocol and

tested material. Unfortunately, there is no single procedure that works for all rheometers and there is no rheometer that works for all materials. Hence, the search of reliable way for rheological properties diagnostics is still being continued. For these aims researchers suggest the different methods for the rheological properties control: oscillatory rheology [17], ultrasonic spinning rheometry [18], rotational viscometer and dynamic shear rheometer [19].

The workability of mortar and concrete could be evaluated in terms of their flowability and deformability during pumping and filling operations. However, there is no rheological criterion yet upon which the dynamic stability could be evaluated [20]. To predict and control the concrete behavior numerous studies are performed in [21]. The results demonstrate that there is no clear relationship between flow resistance and piston pressure. By contrast, fairly good statistical correlations exist between torque viscosity and piston pump pressure. Therefore, the torque can be the rheological parameter for the mortar and concrete workability. Based on this, the special sensors can be acceptable for diagnostics of injection mortar rheological properties. These sensors consist of two parts – mechanical and electrical. The mechanical part contacts with mortar and electrical one is placed outside mortar or isolated from it. The sensor can be proposed as such device in [22] and in which the electric motor translationally moves a spherical spindle inside the mortar. This sensor is based on amperage conversion on the motor shaft to the rheological characteristics with the usage of dependencies determined earlier. But for the such system the dependencies have not still been established between the mortar rheological properties and the mortar viscosity which are necessary for penetration ensuring into the whole interpipe gap as well as the dependencies are not established between the mortar penetration depth into gaps, cracks, seams, and the mortar rheological properties. The influence the water quantity in the mortar and quantity of plasticizing additives on the mortar rheological properties is not established either.

3 Theoretical bases and experimental studies

To define the above mentioned dependencies a flow process of cement mortar (suspension) as a water-dispersion system is analyzed in the annular gap (slotted gap for crack) with thickness a. The mortar flows in the annular gap (crack) under pumping pressure p while an external pressure opposes it. The external pressure is formed by the ground water pressure or water pressure p_h which remains after washing of the interpipe gap. Also the external pressure includes the pressure p_f formed by friction force F along gap walls. As a result of pressure equalization, a stationary flow with speed v is installed. Since the penetration is performed at depth l during injection time τ it can be taken

$$v = l/\tau, \text{ m/sec.} \quad (1)$$

In case of a big gap thickness a and filling gap by water, the effects considering meniscus formation can be neglected. According to the Poiseuille's flow law the internal friction force equals

$$F = \eta S_s v/\delta, \quad (2)$$

where η is the effective dynamic viscosity of the mortar, s/m^2; v/δ is the mortar flow rate gradient, 1/s; δ is the mortar near-wall layer thickness in which water speed is changed from 0 to v, m; S_s is the gap surface area, m^2

$$S_s = [\pi d + \pi(d+a)]l = \pi l(2d+a), \quad (3)$$

where d is internal diameter of the annular gap, m.

After substitution (3) in (2) it is obtained

$$P_f = \frac{F}{S} = \frac{\eta S_s v}{S\delta} = \frac{\eta v \pi l(2d+a)}{\pi h(d+0.5a)\delta} = \frac{2\eta v l}{a\delta}, \quad (4)$$

where S is an annular gap surface area, m^2

$$S = \pi(d+0.5a)a = \pi a(d+0.5a). \quad (5)$$

The stationary flow is installed under condition

$$p = p_h + p_f. \quad (6)$$

Having substituted (4), and then (1) in (6), it is obtained

$$p - p_h = \frac{2\eta v l}{a\delta} = \frac{2\eta l^2}{a\delta\tau}. \quad (7)$$

After transformation (7), the mortar injection depth dependence in the gap from the gap thickness a and a mortar viscosity η is obtained

$$l = \sqrt{\frac{(p-p_h)a\delta\tau}{2\eta}}, \quad (8)$$

and the viscosity dependence η which is required for the penetration depth ensuring l in the gap thickness a

$$\eta = \frac{(p-p_h)a\delta\tau}{2L^2}. \quad (9)$$

Investigate the dependence of the mortar penetration depth l (8) as a function of the interpipe gap thickness (crack disclosing) a. The bounding conditions are the quantity characteristics of the reviewed constructions and technologies: the repair section length – less than 100 m; the annular gap thickness – 0÷20 mm in a bench flume and less than 100 mm in an arch; the proof-test pressure – less than 0.16 MPa (it is limited in a pump possibility and pipe strength); the proof-test pressure time – about 10 min; the mortar working life – bigger than an hour (it is limited in an injection duration).

For calculations on (9) the hydrostatic pressure of water which is displaced during proof-test pressing is taken equal for the case when water ground level is higher at 3 m from a sewer pipe. So, the water column height h = 3 m, and the hydrostatic pressure equals

$$p_h = \rho \cdot g \cdot h = 1000 \cdot 9{,}81 \cdot 3 \approx 30000 \text{ Pa},$$

where ρ is the water density, 1000 kg/m^3; g is the gravity acceleration, 9.81 m/s^2.

The proof-test pressure p is accepted equal 160000 Pa, the proof-test pressure time τ is assumed to be 600 s. The mortar near-wall layer thickness δ in which water speed is changed from 0 to v is assumed to be $2.5 \cdot 10^{-5}$ m for the mortar without additives, and $0.8 \cdot 10^{-6}$ m for the mortar with additives [23, 24]. After appropriate substitutions the equation (8) takes the form for the mortar without and with additives, accordingly

$$l = 31.2 \cdot (a/\eta)^{0.5}; \; l = 55.9 \cdot (a/\eta)^{0.5}. \qquad (10)$$

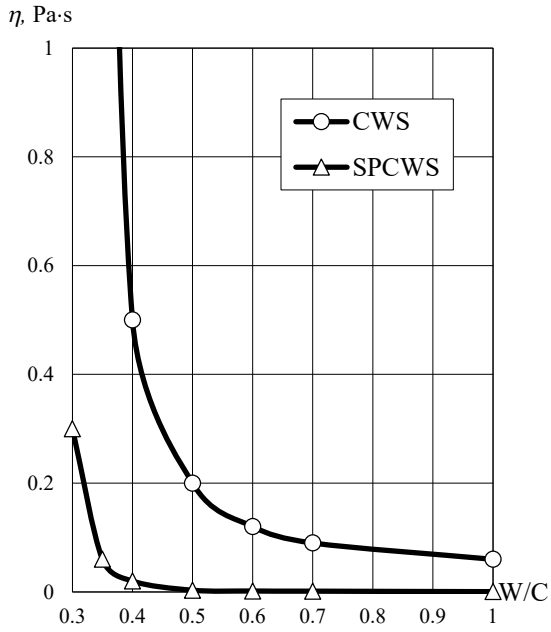
The hardened mortar should possess water impermeability which is not less than concrete impermeability of the pipes used for free-flow collectors building. The concrete water impermeability of such constructions should be W4 according the National Standard [25]. The number "4" means the pressure in atm under which the water penetration does not occur after keeping the concrete samples during determined time under pressure. For concrete the mentioned impermeability class is provided with water-cement ratio (W/C) less than 0.6. Since the concrete permeability is mainly depended on the cement stone properties, it is necessary also to accept W/C less than 0.6 for the injection mortar. The impact degree of an operational medium to the sewer collector is highly aggressive chemical environment XA3 according to [25, 26] taking into account pH value. Under this condition the concrete water impermeability class should be increased to W8 which is provided with W/C less than 0.45. Therefore, the mortar W/C value for the interpipe gap cementation should be taken not more than 0.45 but it is advisable even less based on the conditions ensuring the water impermeability and corrosion resistance as well as durability of the collector constructions. Such W/C ratios can be achieved only with the usage of cementitious mortar with additive-superplasticizers based on the conditions mortar pumping by pumps.

Define the experimental dependencies between dynamic viscosity and W/C ratio. The dynamic viscosity values have been determined with the usage of the rotational viscometer. For studies the cement-water suspension has been performed with different water-cement ratios and addition of the superplasticizer (sodium salt of polymethylene poly-naphthalene sulfonic acid). The experimental results are given on the Fig. 3.

For calculations on the formula (10) the mortar dynamic viscosities η are taken according to Fig. 3:
- for the mortar without additives with W/C = 0.6 – 0.125 Pa·s, with W/C = 0.45 – 0.27 Pa·s, with W/C = 0.35 – 2.33 Pa·s;
- for the mortar with additive-superplasticizer with W/C = 0,6 – 0,002 Pa·s, with W/C = 0.45 – 0.01 Pa·s, with W/C = 0.35 – 0.061 Pa·s.

Graphic presentations of the calculations by formula (10) are given on Fig. 4.

As it follows from Fig. 4 the cement mortars without additives with W/C= 0.45÷0.6 do not penetrate into the interpipe gap for the distance more than 40 m.



CWS – ordinary mortar (cement-water suspension);
SPCWS – mortar with additive-superplasticizer (superplasticized cement-water suspension)

Fig. 3. The dependence between the cement mortar dynamic viscosity η and the water-cement ratio *W/C*.

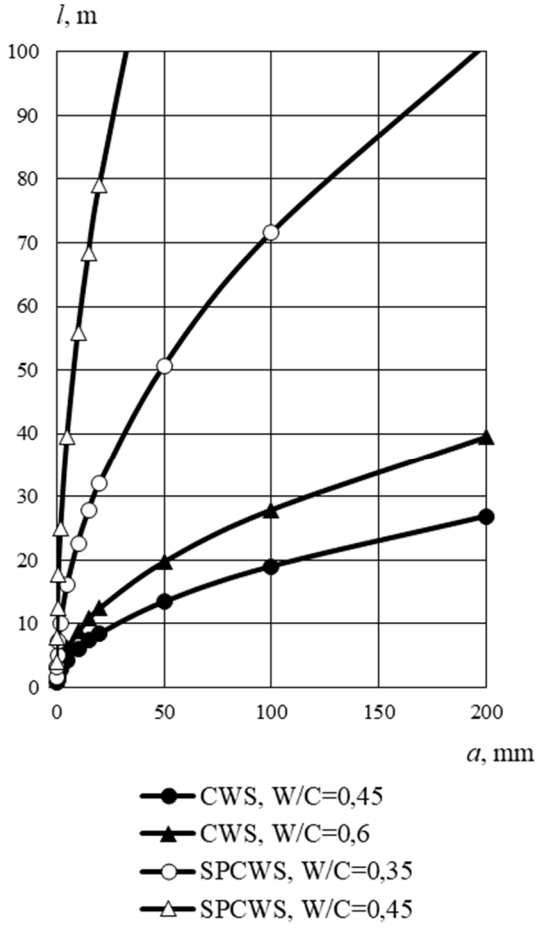


Fig. 4. The dependence between the penetration depth *l* of the injection mortars and the interpipe gap width (crack) *a*.

The mortars with additive-superplasticizers with W/C = 0.35÷0.45 penetrate for the distance to 100 m. Such W/C ratios provide the necessary water impermeability and corrosion resistance of a cement stone. Thereby the cement mortar with W/C not more 0.45 should be applied for cementation of the interpipe gap during a new pipeline arrangement inside damaged sewage collectors. When the repair section length is not more than 20 m the mortar without additives is suitable for the usage. If the length is from 20 m to 100 m the usage of additive-superplasticizer is required.

To sum, the dependence (9) between the required mortar viscosity and the interpipe gap width as well as the repair section length (penetration depth) is applicable for the automatic diagnostic system. The dependence the W/C ratio as a function the required viscosity can be obtained after an approximation of the dependencies given on Fig. 4.

4 Algorithm development for automatic system

Among the automatic systems for diagnostics and regulation of the building object parameters there is a system which allows diagnosing the wet state and stability of the ground massive [27]. This system uses the coaxial sensors with capillary backfill contacting with ground. The bigger soil wet the bigger backfill wet. The sensor measures electrical resistance or electrical capacitance of the backfill. Then these values are digitized and transformed to the ground wetness parameter using the analytical dependencies. The system informs an operator about the moisture amount. If it is provided for, the system generates control signal for actuating mechanisms which perform draining or fixing the ground. If suchlike mechanisms are absent the system recommends to the specialist to choose certain methods for draining or fixing the ground. However, this system is automatic in part and expert partially. Besides the used sensors are suitable for not too large quantities of wetness for dispersed material such as soil. These values can be significantly less than the water content of the injection mortar. Also, such sensors are not applicable in case of an addition of the hardening accelerators-electrolytes into the injection mortar.

The magnitude of the mechanical effort to move the mobile part of the device to measure the shear stress can be converted into an electrical signal. For this research, an electromechanical device ES-1 (Fig. 5) was developed in which the measuring spindle is a sphere which is driven by the electric drive and moves at a constant speed. The measuring scale is an ammeter, which shows the strength of the current on the shaft of the electric motor and which is pre-set with the desired workability index of the mortar. A control signal is taken from the shaft of the electric motor, for the automated control system to prepare the building mortar. The current strength can be used as the conventional viscosity of the mortar, and the dependence can be applied to automatic maintenance of water content and given technological characteristics.

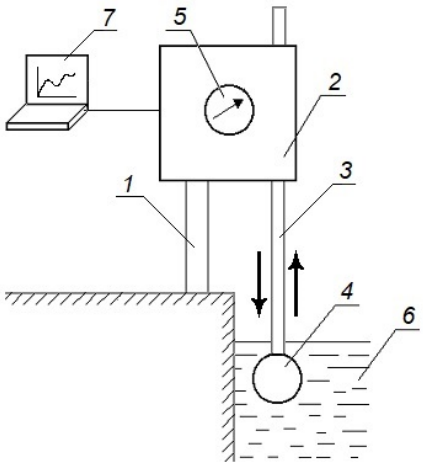


Fig. 5. Electromechanical device for determining the rheological and technological characteristics of building mortars: 1 – tripod; 2 – electric drive; 3 – rod; 4 – spherical spindle; 5 – ammeter; 6 – building mortar; 7 – computer.

An algorithm of the developed automatic system for diagnostics and regulation of rheological properties for the cement injection mortars is given on Fig. 6. The algorithm functions in the following way. The operator, who performs the system work, with the help of statement *2* inputs the values of the length L, the interpipe gap width δ, the maximum permissible deviation of mortar viscosity $\Delta\eta_{max}$, the maximum permissible water content in mortar W_{max}, the interpipe gap volume V_{max} including hollows and cavities in the damaged places, the mortar mixer volume of discrete action v. Statement 3 calculates the permissible mortar viscosity η depending on L and δ, and operator 4 counts the water consumption W depending on η.

Statement 5 assigns the value 0 for number of the mortar preparation cycle i. Statement 6 compares the water consumption W with the maximum permissible water content in mortar W_{max}. If $W > W_{max}$, statement 7 assigns W the value W_{max}, and statement 8 calculates the additive-superplasticizer consumption A depending on W_{max} and the required mortar viscosity η. If W is not bigger than W_{max}, statement 9 assigns the value 0 for the additive-superplasticizer consumption A. Statement 10 increases the number of the mortar preparation cycle i by 1, and statement 11 outputs the number of the mortar preparation cycle i, the consumption of water W and additive-superplasticizer A, the required viscosity η for information of the specialist, as well as transmits the value W and A to actuating mechanisms of batchers.

The batchers dose the mortar components into the mortar mixer that prepares the mortar. After that the mortar viscosity diagnosing is performed by the electric drive-ball sensor, and the mortar is pumped by the pump through the mortar conduit into the gap. Amperage I from the sensor of the motor shaft is digitized with the usage of a converter and input in the algorithm by statement 12.

Statement 13 converts amperage to the mortar viscosity η_i. Statement 14 counts the mortar total amount V which entered into the gap after i-th cycle, and statement 15 compares the obtained value V with maximal volume

of the interpipe gap V_{max}. If $V < V_{max}$ statement 16 calculates the deviation made by the diagnostic system, the viscosity value η_i from the demanded viscosity η.

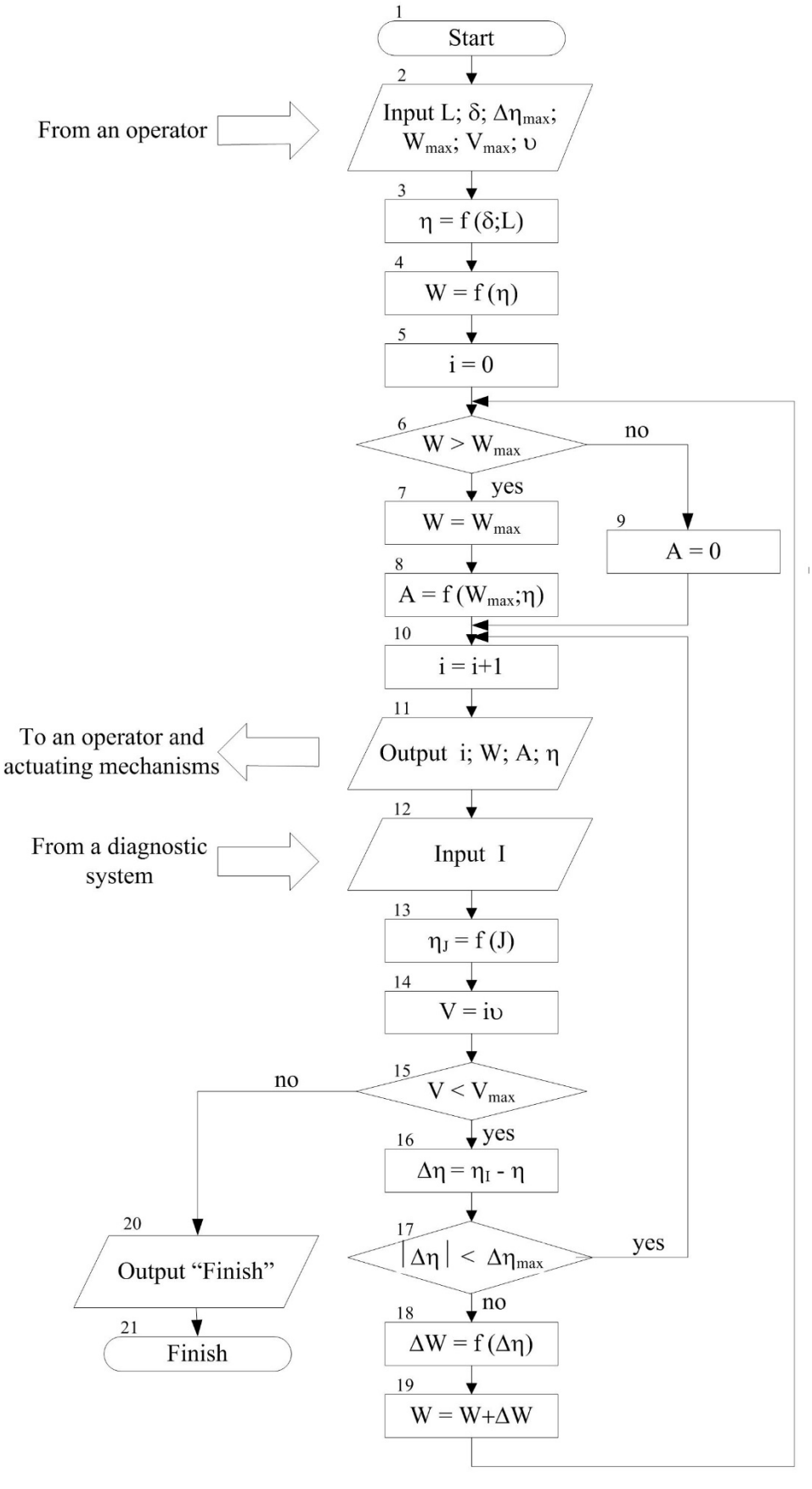


Fig. 6. Functioning algorithm of the diagnostic and regulation system of the injection mortars rheological characteristics.

Statement 17 compares the absolute value of the viscosity deviation $|\Delta\eta|$ which is defined by statement 16 with the maximum permissible value $\Delta\eta_{max}$. If $|\Delta\eta| < \Delta\eta_{max}$ statement 17 returns the executing programme to statement 10. If $|\Delta\eta|$ is not less than $\Delta\eta_{max}$ statement 18 calculates the correction of the water consumption ΔW depending on the viscosity deviation $\Delta\eta$, and statement 19 counts the new corrected water consumption W and returns the executing programme to statement 6. If V is not less than V_{max} statement 20 reports about the work completion, and statement 21 ends it.

Conclusions

1. The electromechanical sensor is chosen for the automatic diagnostics and regulation system of the rheological characteristics for the injection mortars which are used for repairing the sewage pipes by the insert method. The sensor mechanical part contacts with the mortar but the electric part is placed outside the mortar. An electric signal – amperage – is removed from the motor shaft which translationally moves a spherical spindle inside the mortar. After digitizing the amperage is transformed to the mortar viscosity value.
2. The dependencies between the mortar viscosity, the penetration depth, and the water-cement ratio of the cement mortar both without the additives and with the additives-superplacticizer are received. These dependencies are applicable for the automatic diagnostic and regulation system of the rheological characteristics for the injection cement mortars.3. Functioning algorithm of the automatic diagnostic and regulation system of the injection mortars rheological properties is developed for cementation of the interpipe gap during repairing the sewage pipes by the insert method. The system application allows increasing of the cementation quality, corrosion resistance and durability of the repaired pipeline section as well as decreasing the work duration and labor costs.

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Sustainable low-carbon binders and concretes

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Abstract. Sustainable development depends on a consistency of interests, social, ecological and economic, and that the interests are evaluated in a balanced manner. In order to reduce CO_2 emissions, the conception of decreasing clinker factor and increasing the role of supplementary cementitious materials (SCMs) in the cementitious materials has high economical and environmental efficiency. The performance of clinker-efficient blended cements with supplementary cementitious materials were examined. The influence of superfine zeolite with increased surface energy on the physical and chemical properties of low-carbon blended cements is shown. Increasing the dispersion of cementitious materials contributes to the growth of their strength activity index due to compaction of cement matrix and pozzolanic reactions in unclincker part. In consequence of the early structure formation and the directed formation of the microstructure of the cement matrix is solving the problem of obtaining clinker-efficient concretes. Shown that low-carbon blended cements with high volume of SCMs are suitable, in principle, for producing structural concretes.

1 Introduction

The development of civilization, such as urban expansion or infrastructure development, has a significant environmental impact. Excessive consumption of energy leads to a significant increase in the amount of carbon dioxide in the atmosphere, which causes climate change and threatens the future of humanity. At the same time there are problems of waste disposal and reduction of consumption of natural raw materials. Therefore, the crucial topic of the functioning of civilization in the XXI century is the concept of sustainable development [1, 2]. The priorities identified at the World Summit on Sustainable Development are the integration of these three components: economic growth, social development and environmental protection. Currently, the challenge of introducing principles of sustainable development in the construction sector, especially in the industry of construction materials, is extremely urgent. This implies the creation of technical prerequisites that form the basis for the development and implementation of effective measures to improve the energy efficiency of construction technologies in accordance with environmental requirements, taking into account the full life cycle of products and objects. The basic principles of sustainable development strategy in the cement industry are to optimize the usage of non-renewable natural raw materials: the implementation of resource-saving technologies; utilization of industrial waste, as well as comprehensive environmental protection and reduction of CO_2 emissions [3-6].

The Paris Agreement was adopted in accordance with the UN Framework Convention on Climate Change (UNFCCC) in order to regulate carbon dioxide reduction measures from 2020 replacing the Kyoto Protocol. This climate agreement stipulates that commitments to reduce harmful greenhouse gas emissions to the atmosphere and not to exceed rising temperatures above 2 degrees Celsius shall be observed by all states, regardless of their level of economic development.

The EU's priority is to reduce greenhouse gas emissions by 80-95 % by 2050. The cement industry produces a significant amount of greenhouse gases, accounting for 2-2.5 gigatons of CO_2 or 6.5 % of the total anthropogenic emissions worldwide. Integrated cement industry solutions for sustainable development policies aim at reducing CO_2 emissions by reducing high-energy Portland cement clinker in composition of cement by utilizing industrial waste, improving production technology and using alternative fuels. Additional emission reductions can be achieved through the use of new technologies such as carbon capture and storage (CCS) and low carbon cement replacement components [7]. With this policy and technological prerequisites, a potential reduction in CO_2 emissions of up to 80 % can be achieved [8]. The production of high-tech products in the construction industry, taking into account the reduction of environmental pollution, is largely realized through the introduction of effective low-emission (low-carbon) cements and concretes based on them [7].

The EU Roadmap 2050 on low-carbon economy with regards to cement and concrete industry envisages five parallel directions, each contributing to the reduction of CO_2 emissions. According to the roadmap, the first direction involves reduction of the usage of natural resources, increasing the share of alternative fuels,

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replacing clinker with mineral components and introducing new types of cement, which will allow to replace a significant proportion (up to 80 wt.%) of high-energy Portland cement clinker in cement-containing materials. including production wastes. The use of SCMs in cement production has a positive impact on the economic aspect of production and, crucially, is a significant factor in improving the environment. On the other hand, the use of industrial waste can reduce the consumption of natural raw materials, reduce CO_2 emissions and free up useful soils, which will reduce the risk of man-made disasters and contribute to the energy independence of the national economy [8].

The family of common cements according to EN 197-1 are divided into five types: CEM I – Portland cement; CEM II – Portland cement with additives; CEM III – slag Portland cement; CEM IV – pozzolanic cement; CEM V – composite cement. Portland cement CEM I can contain up to 5 wt.% of mineral additives. The content of mineral additives in cement from CEM II to CEM V can vary over a wide range – from 6 to 80 wt.%. In the European standard EN 197-1 are selected as a separate type of composite cements, which according to the requirements must contain at least two types of mineral constituents of different nature of activity (hydraulic and pozzolanic action).

The solution to the problem of energy saving and reduction of CO_2 emissions in the cement industry is largely determined by the search for structural, logical and environmental ways of replacing part of the Portland cement clinker with secondary components with optimization of particle size and material composition of cement. The result of such efforts is a plan of amendments to the standard for general purpose cements EN 197-1 regarding the introduction of new types of composite cements of types CEM II/C and CEM VI [9].

Due to the environmental impact of the cement industry in the direction of sustainable development, by selecting appropriate combinations of non-clinker components in low-carbon cements will be an alternative to traditional cements [10-13]. At the same time, more and more attention are paid to the production of low-carbon concretes. The evaluation of the environmental impact indicator for binary and ternary cements has made it possible to determine their suitability for the production of low-carbon concrete.

The concept of creating modified concretes and mortars involves the use of multicomponent cements with a high content of SCMs and optimization of their component composition and particle size distribution due to the combination of mineral components of natural and man-made origin, nanoadditives and alkaline activation [14-17]. This will facilitate the acceleration of hydraulic and pozzolanic reactions in the SCMs system; improving the transition zone between the cement matrix and the aggregate. Increasing the content of finely dispersed energy-active fractions in the SCMs will increase the surface area of the active phases, which increases the rheological effect of the polycarboxylate modifier on the mixture. The effectiveness of this idea is to maximize the disclosure of the synergistic role of ultrafine mineral components in low-emission multicomponent cements, which will have a direct impact on the processes of regulating the properties of clinker-efficient concretes.

According to data from K. L. Scrivener et al. [5], binder intensity for concretes with a strength of 60 MPa should be within the range of 2-5 kg per 1 MPa of concrete strength (Fig. 1). Binder intensities around 4-5 kg/m^3·MPa can be achieved for 50 MPa concretes and more with by optimizing the component composition of concrete and using new generation water-reducing admixture. Similar way can be deployed for mortars, concrete blocks and other cement-based products.

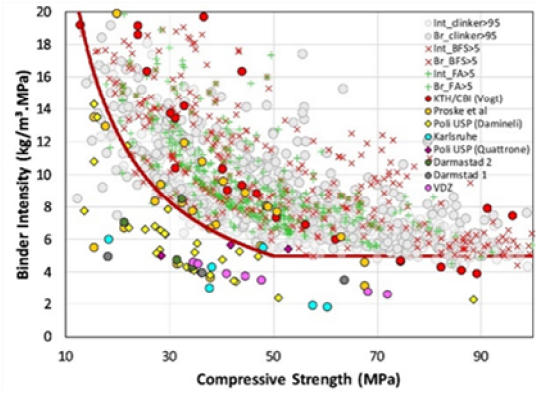

Fig. 1. Potential CO_2 mitigation by optimizing binder use with current and high-filler, low-water technologies [7].

In advanced EU countries, CO_2 emissions for concrete have been reduced by 19.1% and account for 83.4 kg of CO_2 per tonne of concrete. To reduce ECO_2, it is also foreseen to replace the proportion of Portland cement CEM I pure cement in concrete with multicomponent SCMs, which is an actual way to achieve a sustainable development in construction.

2 Materials and methods of research

2.1 Materials

Commercially available Ordinary Portland cement (OPC) CEM I 42.5R (Manufacturer – JSC "Ivano-Frankivsk Cement", Ukraine) was used as reference cement in the investigation. The contents of the main clinker phases were as follows, mass. %: C_3S – 60.2; C_2S – 4.25; C_3A – 7.20; C_4AF – 11.85. Supplementary cementitious materials as ground granulated blast furnace slag (GGBFS, Kryvyi Rih), zeolite tuff (Z, Sokyrnytsky quarry), fly ash (FA, Burshtyn TPP), and limestone powder (LL, Dubivetske quarry) were used to obtain low emission binders. The chemical composition of SCMs is shown in Fig. 2.

Building binder G-6 brand based on calcium sulphate hemihydrate ($CaSO_4·0.5H_2O$) was used for development low-carbon gypsum binder.

The high-performance Master Glenium ACE 430 (BASF) polycarboxylate ether (PCE) superplasticizer was used as a modifier for concrete and air-entraining admixture MasterAir 81 (BASF) was used to improve the quality parameters of mortars.

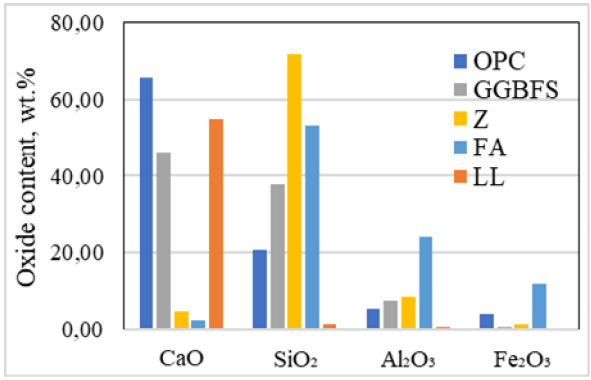

Fig. 2. Chemical composition of SCMs.

Sand of Zhovkva deposit, Ukraine, was used as fine aggregates (FA) and crushed stone of Virovske deposit, Ukraine, as coarse aggregates (CA) were used to design of mixture compositions.

Blended cements (CEM II/B-M, CEM IV/B, CEM V/A, MC 22.5X) with the different ratio between Portland cement CEM I 42.5R and supplementary cementitious materials were used in experiments (Table 1).

Table 1. The composition of cements.

Cement	Clinker factor	OPC	GGBFS	Z	FA	LL
CEM I	0,95	100	-	-	-	-
CEM II/B-M	0,65	65	20	10	-	5
CEM IV/B	0,50	50	-	27	23	-
CEM V/A	0,50	50	25	20	-	5
MC 22.5X	0,40	40	-	40	-	20

2.2 Methods

Investigation of the chemical composition of OPC and SCMs was carried out using an X-ray diffractometry ARL (OPTIM'X) 9800XP. Blended cements were obtained by mixing OPC and SCMs in a laboratory ball mill. The physical and mechanical properties of blended cements were determined in accordance with current standards and generally accepted methods. For determining the strength class of cement according to EN 196-1 the specimens (40x40x160 mm) of the mortar based on investigated cement were prepared. After disbandment and marking, the samples were placed in water for storage until the test was performed at 2, 28 and 365 days.

To establish relationship between ecological and technical properties of concrete, clinker efficiency coefficient in concrete was determined as the ratio of cement consumption to compressive strength in a certain age [kg/(m^3·MPa)]. Compressive strength of nanomodified concretes was determined on cubic specimens (100x100x100 mm) after 1, 2 and 28 days.

3 Research results

Component composition of blended cements have a significant influence on the process of the compressive strength. The compressive strength of cements at age of hardening 2; 28 and 365 days is shown in Fig. 3. Early strength of blended cements is lower compared to OPC, because SCMs are characterized by lower activity than Portland cement clinker. However, after 28 days of hardening the strength of the blended cements CEM II/B-M, CEM IV/B, CEM V/A increases and corresponds to the strength class 32.5 R and MC - the strength class 22.5X. Coefficients of CO_2 emission of blended cements with different clinker-factor are presented at Fig. 4.

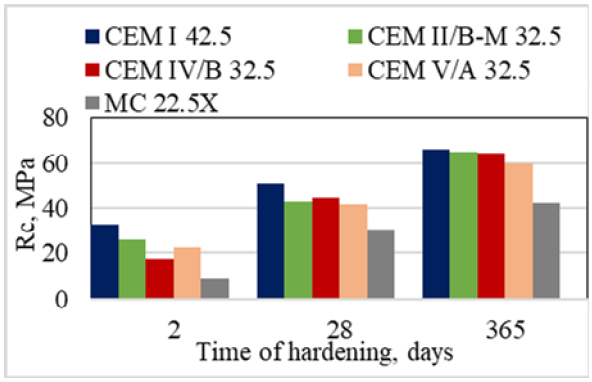

Fig. 3. Compressive strength of cements.

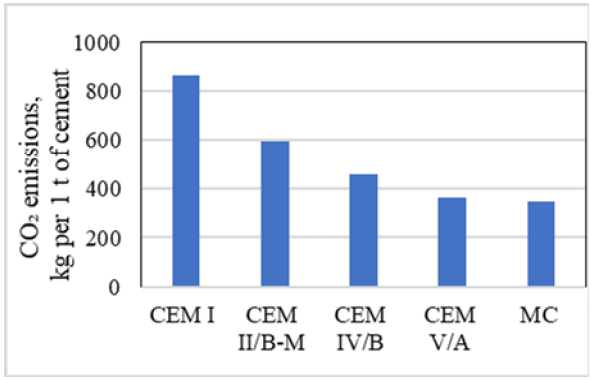

Fig. 4. CO_2 emission of blended cements with different clinker-factor.

To determine effects of formulation and technological factors, concrete mixes compositions were designed using mathematical experiment planning. Experimental studies of impact of composite Portland cement CEM II/B-M and PCE superplasticizer consumption on early strength as well as clinker efficiency coefficients in concrete were performed according to a two-factor three-level experiment. Consumption of CEM II/B-M (X_1=320; 370; 420 kg/m^3) and amount of PCE (X_2=0; 0.8; 1.6 wt. %) were chosen as variable factors.

The increase of cement usage from 320 to 420 kg per m^3 to achieve OK=16–18 cm, a decrease in W/C from 0.62 to 0.48 was observed. After 2 days of curing, modified concrete with cement amount of 420 kg/m^3 and PCE of 1.6 wt. % had the highest strength (f_{c2}=47.0 MPa). Calculations of concrete clinker efficiency revealed that with an increase in strength of concrete, specific consumption of clinker per unit of strength is 3.5…3.1 kg/m^3 MPa after 28 days. The modified clinker-efficient concretes classes C35/45…

C40/50 are characterized by average increase of strengh (fcm_2/fcm_{28} = 0.32…0.39).

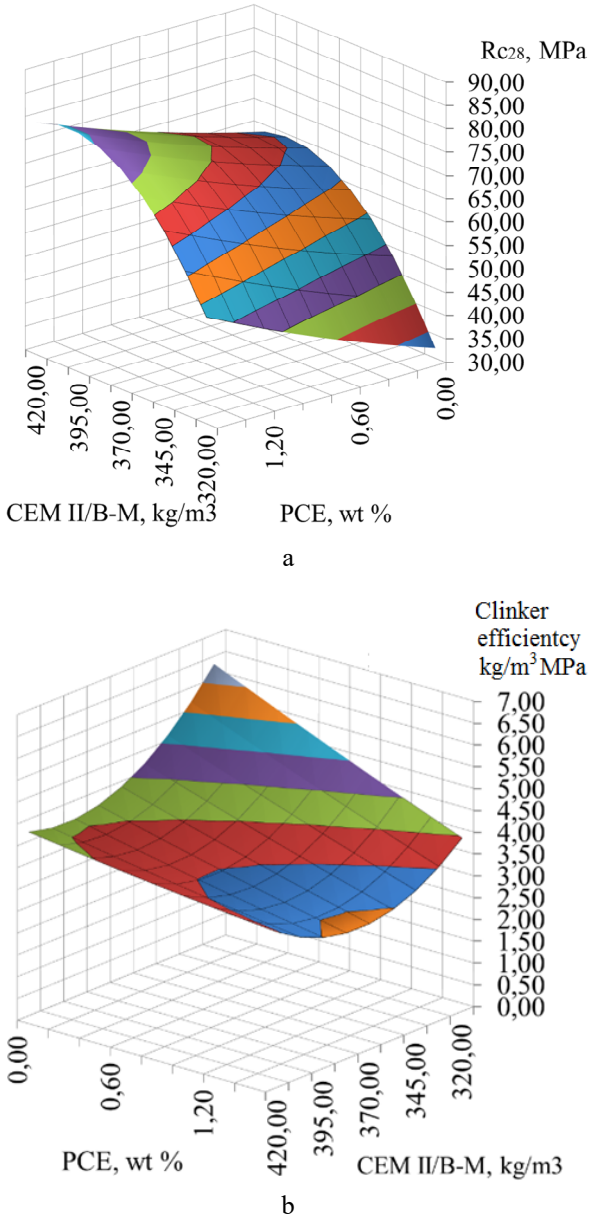

Fig. 5. Response surfaces after 28 days of hardening: concrete strength (a) and clinker efficiency (b).

Concretes with W/C = 0.38-0.42 were designed to study the quality parameters of modified concrete based on low-carbon binders CEM II/B-M 32,5 R, CEM IV/B 32,5 R, CEM V/A 32,5 R, MC 22,5X. Composition of concrete by weight C: FA: CA = 1:1,87:3,6 (cement – 370 kg per 1 m^3). For determining workability of fresh concrete mix was measured slump of a compacted concrete cone (under the action of gravitational forces) which equal to 9.5..15.0 cm. The density of fresh concretes are 2260..2410 kg/m^3 and air content amount to 2.6..4.5 %. For the investigated concrete mixes there are no bleeding due to the content of superfine zeolite in the composition of blended cements, because zeolite is characterized by porous structure and a low bleeding than GGBFS, fly ash and limestone. The strength of clinker-efficient concretes is presented in Fig. 6 and the conformity of the developed concretes based on low-carbon cements to the Cement Industry' road map is shown in fig. 7.

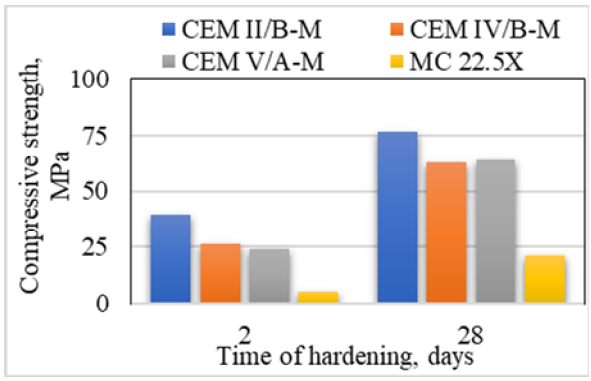

Fig. 6. Strength of clinker-efficient concretes.

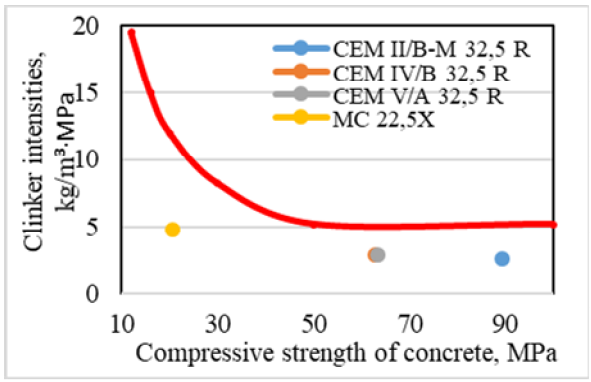

Fig. 7. Sustainable concretes based on low-carbon cements.

The possibility of using multicomponent cements in construction technology is largely determined by the properties of mortars based on them. Experimental studies have established the amount of low-carbon binder MC 22.5X for the design of mortar classes M2.5 ... M10. For mortar mixes (consistency by plunger 30-35 mm) water-cement ratio increases from 0.75 to 1.3 with reduction consumption of cement MC 22.5X from 465 to 198 per 1 m^3 of sand. The bulk density of masonry mortars varies from 2050 to 1995 kg/m^3. As can be seen from Fig. 8, a, class M10 by the compressive strength for masonry mortar is achieved at the consumption of low-carbon binder 465 kg/m^3. The consumption of MC 22.5X is 232… 348 kg/m^3 to provide the class M2.5...M5. Experimental studies have found that with the using 0.09… 0.18 % Master Air 81 admixture with plasticizing and air-entraining action in the composition of mortars (consumption of MC 22.5X – 465…198 kg/m^3, consistency by plunger 30-35 mm) water content is reduced by 10-15 % and bulk density – to 1880…1820 kg/m^3. The strength activity index after 28 days increases 1.3-1.1 times, after 90 days – 1.5-1.2 times compared to mortars without Master Air 81 (Fig. 8, b). Modified mortar with a MC 22,5X consumption of 465 kg/m^3 is characterized by the highest strength 21.0 MPa.

Consistent efforts with the goal of significant reduction of emissions of CO_2 are directed to research the chemistry of cement that ensures partial or complete replacement of ordinary Portland cement by ecologically

friendly binders [18]. Currently, the consumption of calcium sulphate plasters increases as they belong to the most ecologically friendly binders because of their low energy consumption during the production. Nevertheless, gypsum products have low water resistance. Improved structural and technical qualities of gypsum products, in particular their increased strength and water resistance are ensured by these two methods: the creation of products with low coefficient of water/gypsum or the introduction of Portland cement and active mineral additives to the gypsum binder [19, 209].

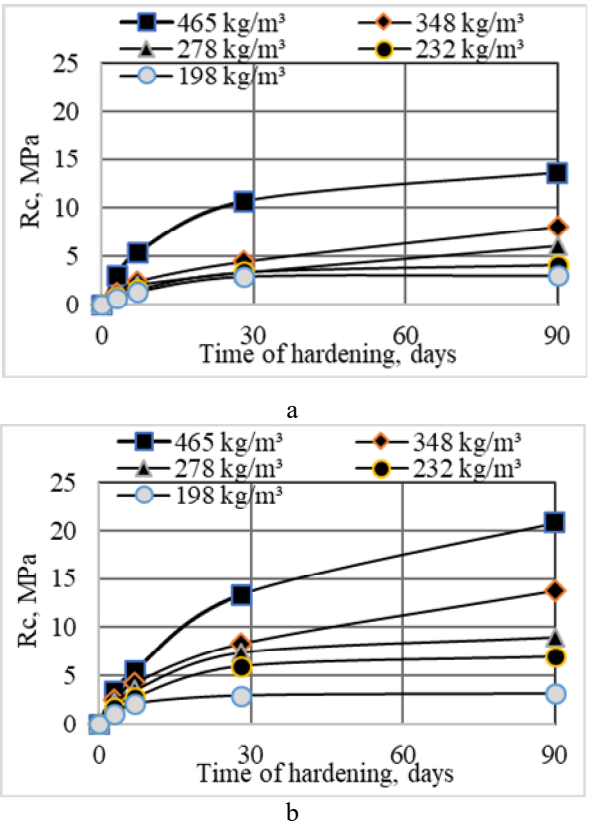

Fig. 8. Compressive strength of mortars based on MC 22,5X: without admixture (a); with Master Air 81 (b).

In gypsum binder, the carbon footprint factor (140.7 kg CO_2/t) is lower by 4.0–6.0 compared to Portland cements. However, the gypsum binder is characterized by a very low (5.0-7.0 MPa) compressive strength and low water resistance. Combining different types of binding substances allows production of strong and water resistance low-carbon dioxide emission composites. The strength of a composite binder based on 75 wt.% G-6 + 25 wt.% MC22.5X in 28 days reaches 20 MPa and in 2.3 times exceeds the strength of building plaster. Due to hardening because of pozzolanic reaction, the strength increases even more and the water resistance corresponds to the hydraulically hardened binders. Simultaneously, the carbon footprint (163.0 kg CO_2/t) of this composite binder is only by 15.8 % higher than one of building plaster, but is significantly lower in comparison to ordinary Portland binder.

The zeolite-based composite plaster binders modified by polycarboxylate's superplasticizers are even more strength and softening coefficient (Fig. 9). They are water resistant, durable and can be utilized for the production of building mortars, dry mixtures for plaster, restoration works, as well as partitions and walls in wet rooms, for the formation of bulky elements of sanitary cabinets, for devices of self-leveling screeds under a floor.

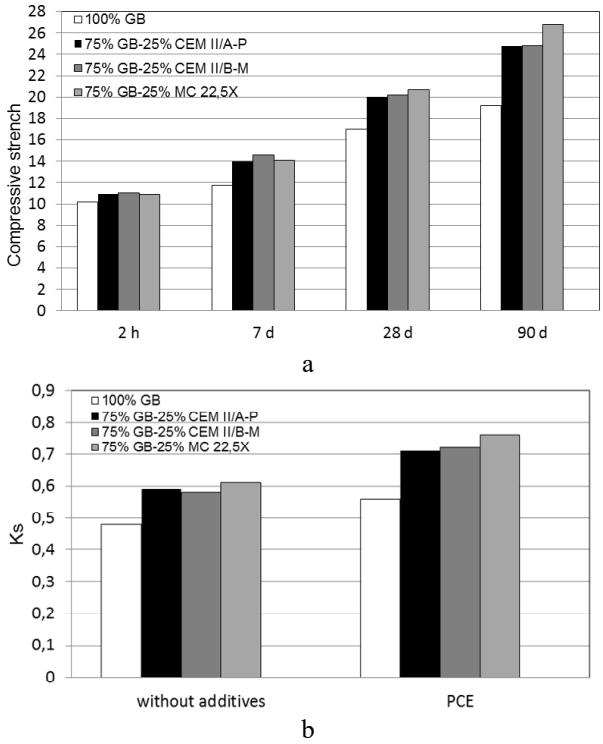

Fig. 9. Compressive strength (a) and softening coefficient (b) of composite gypsum binders with PCE admixture.

Particularly noteworthy is the use of composite gypsum binder for the manufacture of lightweight concrete – arbolite based on composite binders, organic fillers (up to 50-60 % of the volume) and chemical additives [21]. Blocks using composite binder based on gypsum, cement and superzeolite, as well as hemp as a filler are sustainable, heat resistant, humidity-free – and carbon negative. A hemp houses could be greener, fire-resistant and built quicker than using lightweight expanded clay concrete.

Modified multi-component composite binders containing superfine zeolite and carbonate microfillers can significantly reduce the power consumption during production of various construction materials and decrease carbon footprint, that correspond to the goals of sustainable development in the construction.

4 Conclusions

Development of low-carbon multicomponent cements and modified clinker-efficient concretes and mortars based on them allows to create progressive models of rational use of natural raw materials, fuel, electricity, utilize production wastes, reduce greenhouse gas emissions and solve a number of important environmental, economic and social problems. The urgency of developing the basics of low-carbon cements technologies is in line with the global concept of

sustainable development and life cycle approach with rational use and saving of material and energy resources and is determined by the possibility of reducing CO_2 emissions by 2.5-4.0 times while reducing the content of clinker component.

The compositions of gypsum, Portland cement clinker, pozzolan zeolite-containing components, as well as the use of polycarboxylate superplasticizers allows to produce environmentally friendly modified composite gypsum binders with the increased water resistance. The multicomponent gypsum binders with the preservation of the positive properties of gypsum products and the acquisition of hydraulic properties of Portland cement promotes the development of hydraulic properties, the increase in strength, water resistance and durability of composite gypsum products as a whole. The hempcrete articles based on composite binders are sustainable, heat resistant, humidity-free – and carbon negative.

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Modeling the horizontal movement of bulk material in the system “conveyor – rotary mixer”

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Abstract. In this work, we consider methods for analytical construction of the profile of rotor blades mixer, as well as mathematical modeling of their work on moving and mixing bulk material on a conveyor to increase process efficiency mixing raw materials and optimizing its operating costs. In addition to increasing the effectiveness of the mixing process and lower operating costs, the goal of implementation the proposed methods is the consciousness of production with the least possible errors that would meet modern technical requirements and be adapted to consumer tasks. In this regard, the aim of this work was to determine rational parameters and geometric characteristics of the profile of the rotor mixer blades contributing to improving the quality of mixing the metallurgical charge transported on a conveyor belt. To achieve the goal by modeling, which is a key method of the fourth concept industrial revolution, using the developed mathematical model analyzed the movement of a particle of material along a conveyor belt with its subsequent interaction with the blades of the working body of the rotary mixer.

1 Introduction

To obtain metals and alloys of the required chemical composition and mechanical strength, apply various types of necessary raw materials. Such mixed raw materials, before operations sintering and smelting are called charge materials. Recently, with a deterioration the raw material base of the metallurgical complex of Ukraine, much attention should be paid mixing and other type of equipment capable of existing technological schemes, to improve the quality of preparation of charge materials before sintering and smelting [1], [2]. Implementation the concept of the fourth digital revolution precisely at the mixing stage is promising solution, since such a process is one of the main in technological schemes metallurgical production. Analysis of the works [3], [6], [7] related to the development and improvement of various kinds of continuous mixers in the preparation of bulk materials for their further use shows that such equipment should meet current trends in the development of this kind of technology, namely for metallurgical processes, have high performance and at the same time - the degree of mixing of raw materials with negligible operational and capital costs. However, the improvement of the mixer, made by such a structural scheme, is constrained the lack of theoretical research aimed at studying the movement of material on the blade horizontal mixer installed directly above the conveyor the tape of the transported device. Therefore, the study of the movement of material with blades high-performance mixer, working in conjunction with a layer of conveying raw materials on conveyor belt is an urgent and timely scientific task. In this paper, we consider methods for analytical construction of the profile of rotor blades mixer, as well as mathematical modeling of the movement of bulk material along them and conveyor belt, which allows, based on technological requirements, to determine the necessary rational equipment parameters that enhance mixing efficiency components of the metallurgical charge. In addition, the purpose of consideration and implementation of such methods is the creation of production with the least number of errors that would ensure the necessary product quality adapted to the needs of consumers.

One such mixer in a number technological schemes of metallurgical production can be used mixer continuous with elastic truss elements, the design of which It is rather well described in a number of works [8-12]. However, an improvement on the mixer, made according to such a constructive scheme, constrained by the lack of theoretical research studies the movement of material on the mixer blades horizontally directed action installed directly above conveyor belt transported devices.

Therefore, the study of motion material with high-performance vanes mixer working in conjunction with the layer conveying raw materials on a conveyor belt, is an urgent and timely task. In this paper, we consider the methods: analytical construction of the profile of the blades charge rotor mixer rotor materials in order to increase the term operating equipment for the existing technological scheme for the production of sinter and pellets; material movement on the shoulder blade horizontal mixer actions.

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1.1 Work related sources

The existing rotary mixer with elastic cable elements in [3] has a number of advantages in comparison with batch mixers. They are more effective and can be used in existing technologies without significant investment. However, in [5] a mathematical model was constructed that takes into account additional vibrations that allow the material to move in a state of suspension. This condition allows significantly reduce energy costs during subsequent work, such as mixing.

1.2 Our contribution

This article presents some improvements based on the proposed methodology in [5]. From taking into account additional vibrations, the problem arises of determining the profile of the rotor blades mixer and the interaction of particles of the material with its surface. This article suggested algorithm for constructing the analytical profile of the blade [3] and analysis of the movement of the particle material on its curved surface.

1.3 Work structure

The rest of the paper is organized as follows. Section 2.1 contains preliminary information used in this article that describes the characteristic and principle of operation rotary mixer with elastic elements. Section 2.2 provides a mathematical description. The interaction of the product particles on the surface of the rough profile of the blade when it rotational exit from the material array. Section 2.3 gives an analytical method for determining allowable sector of the process of particle slip. Finally, Section 3 concludes and presents direction for future research.

2 Background

2.1 Rotary mixer design

This type of mixer is shown in Figure 1, for clarity, a section of the front part is made rotary mixer. The principle of this mixer with its design features it is rather well described in a number of works [3], [4], [5]. However, not one of them contains an analysis. the movement of material on the mixer blades, which would have a better idea of him work, and, accordingly, use in those or other technological lines with preparation of metallurgical raw materials production.

Rotary mixer is installed directly to the conveyor belt frame. It consists of a welded frame *1*, sections *2*. In bearing support *3* of each section two rotors are installed. Rotor drive with flexible cable elements *4* carried out by electric motors *5* sousing V-belt transmission *6*. Composite side with V-belt drives *7* are given in blade rotor movement *8*. As sealing section applied lamellar rubber *9* and *10*. At the inlet and outlet of the mixer A sealing rubber curtain is installed on the end walls. Support and regulation the gap between the tape and the rotors is adjusting screws *11*. Side walls sections are closed by fences *12* and *13* in order to prevent injury from rotating parts. Depending on the technology requirements, number of section scan increase or decrease [3].

The principle of operation of a rotary mixer with a flexible cable rotor next: loose material moving on a conveyor belt, enters the mixing zone (which located between the conveyor belt and working elements of the rotor), where it falls under the effect of complex force *4* in rotor with flexible cable elements each section *2* located first on the direction of movement of the conveyor belt and driven by an electric motor *5*. Rotating rotor *4* with its flexible elements that are staggered order for complete overlap of the zone mixing performs integrated impact on the material while loosening and stirring it. Having the ability to change lengths of flexible cable elements, as well as their diameter, can fit rotor with flexible elements for specific conditions technological process. Moving on the material is affected by the blade rotor *8*, which performs more than intensive mixing loosened material.

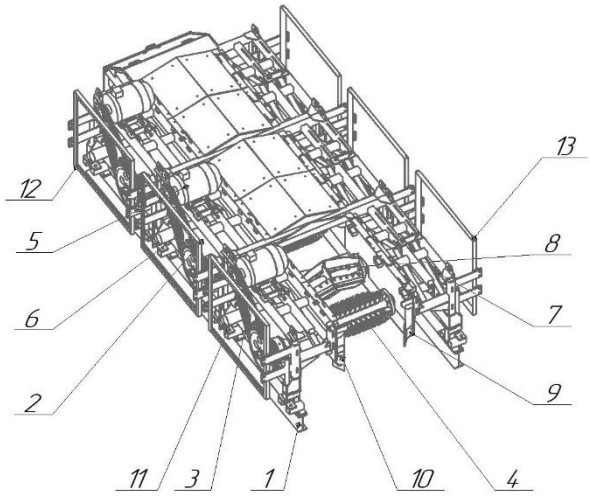

Fig. 1. Rotary mixer with flexible cable element in section [3].

Clearance between work items rotors *4*, *8* and conveyor belt supported thanks to the adjusting screws *11*. This the gap reduces wear on the tape conveyor belt from abrasive friction material on the tape, thereby increasing its life service. The disadvantage of the mixer in questions that he is not standalone and used with conveyor when transporting dry materials.

2.2 Bulk product behavior on rough profile surface blades during its rotational withdrawal from product array

Consider the motion of a material particle along rough surface of a rotating blade mixer.

We assume that when the blade leaves an array of bulk material that moves along the conveyor belt, she as a result of it excavation carries away some of it portion. Consider the possibility of the process release the scapula from the material, located on it, in the process of rotational rotor movements. We assume that slippage between conveyor belt and rotor blades missing. Then the conditional angular velocity of rotation of the rotor ω_r

with the blades is in kinematic correspondence with the linear speed of the conveyor belt *V*.

Let the material particle be on the surface of a rotating rough blade (Fig. 2), where h is the height of the layer of transported material on the conveyor belt. To study the movement particles, we introduce two coordinates of the system, as shown in Figure 3. Absolutely one fixed *xOy* associated with the horizon, and the second *τMn* movable (relative), associated with the tangent to the profile of the scapula. The tangent axis is inclined at an angle to the radius point position vector.

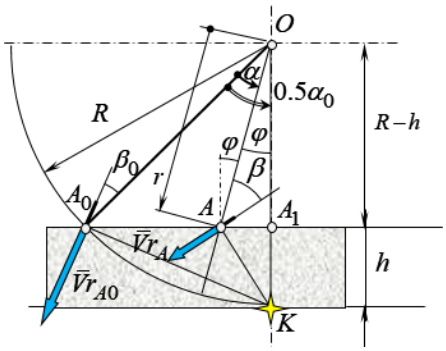

Fig. 2. Explanation of the interaction of the blade with the transported layer of material (shaping of the blades).

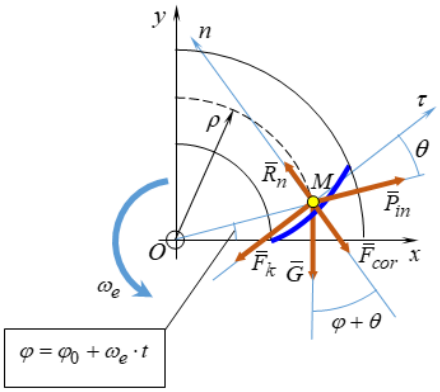

Fig. 3. System of forces applied to material point on the rotor blade making uniform rotation in vertical plane.

The plane of rotation of the blade is located vertically and therefore the action of force gravity per particle in the relative system reference will linearly depend on its angle rotation, from the angle of inclination of the tangent to her profile, as well as from time to time with focus. This dependence may be presented as follows:

$$\begin{cases} G_n = -mg \cdot cos(\varphi + \theta) \\ G_\tau = -mg \cdot sin(\varphi + \theta) \end{cases} \quad (1)$$

Note that with uniform rotation of the rotor its current rotation angle is easy to imagine as a function of time:

$$\varphi = \varphi_0 + \omega_e \cdot t \quad (2)$$

And the angle of inclination of the tangent is a function of the position of the point:

$$\theta = \left(\frac{dy_L}{dx_L}\right) \quad (3)$$

where $\frac{dy_L}{dx_L}$ is the derivative of the profile function of the blade, which, in accordance with the solution differential equation (based on Fig. 2, the condition for the formation of the blade profile is accepted in the diametrical plane of the rotor), we obtain the profile function of the blade

$$y(x) = x \cdot \frac{\sqrt{x^2-(R-h)^2}}{2\cdot(R-h)} - \frac{R-h}{2} \cdot ln\ ln\left[\frac{x+\sqrt{x^2-(R-h^2)}}{R-h}\right] \quad (4)$$

or as a result of which we obtain the following expression for determining the angle *θ*:

$$\frac{dy_L}{dx_L} = \frac{\sqrt{x^2-(R-h)^2}}{R-h} \quad (5)$$

Considering that with this choice of reference systems *x*=*ρ*, we get:

$$\theta = \left(\frac{\sqrt{\rho^2-(R-h)^2}}{R-h}\right) \quad (6)$$

In addition to gravity in the relative system reference to the particle act: inertia force in her portable movement $\overline{P_{in}}$; inertia force from Coriolis acceleration $\overline{F_{cor}}$ (acceleration vector Coriolis directed according to rule Zhukovsky); two forces from imposed bonds – $\overline{R_n}$ (unconditional one-way response kinematic connection) and $\overline{F_k}$ (reaction through Coulon friction).

The force of inertia in a figurative movement is a function of the relative position of the particle

$$|P_{in}| = m \cdot |a_{en}| = m\omega_e{}^2 \cdot \rho \quad (7)$$

The force of inertia from the action of Coriolis acceleration is a function of its relative speed, and modulo takes value

$$|F_{cor}| = 2m\omega_e \cdot \dot{\rho} \quad (8)$$

Resistance force to particle motion in neglected air.

Coulomb friction force of a particle with coefficient of sliding friction *k* about the surface of the blade depends on the pressing force, the value of which corresponds exactly support reactions $\overline{R_n}$ unconditional kinematic connection. The balance of power at relative particle equilibrium in according to the scheme of action of forces in normal to the surface of the scapula will take the form:

$$R_n - F_{cor} - G \cdot cos\ cos\ (\varphi + \theta) = 0 \quad (9)$$

From where we calculate the friction force modulus:

$$|F_k| = k \cdot F_{cor} + k \cdot G_n = k \cdot m \cdot 2\omega_e \cdot \dot{\rho} + \\ + k \cdot mg \cdot cos\left[\omega_e t + \varphi_0 + arctg\left(\frac{\sqrt{\rho^2-(R-h)^2}}{R-h}\right)\right] \quad (10)$$

Based on the basic dynamics equation for relative motion of a material point in accordance with the direction of action of forces, shown in the diagram (Fig. 3), we have:

$$m \cdot \ddot{\rho} = P_{in} - F_k - mg\ sin\times$$

$$\times \left[\omega_e t + \varphi_0 + arctg\left(\frac{\sqrt{\rho^2-(R-h)^2}}{R-h}\right)\right] \quad (11)$$

Or after substituting the input quantities:

$$m \cdot \ddot{\rho} = m{\omega_e}^2 \cdot \rho - k \cdot m \cdot 2\omega_e \cdot \dot{\rho} - \\ -kmg \cdot cos\left[\omega_e t + \varphi_0 + arctg\left(\frac{\sqrt{\rho^2-(R-h)^2}}{R-h}\right)\right] - \\ -mg\, sin\left[\omega_e t + \varphi_0 + arctg\left(\frac{\sqrt{\rho^2-(R-h)^2}}{R-h}\right)\right] \quad (12)$$

where ρ – relative position coordinate particles (its current radius of position); R – maximum rotor radius, or distance between the axis of the rotor and the surface of the tape conveyor belt; h – the height of the layer of bulk product on conveyor belt; $\omega_e = \frac{V}{R}$ – angular rotation speed rotor with blades; V – speed of movement conveyor belt with material on it; k – coefficient particle sliding friction on the surface shoulder blades; m – particle mass; g – acceleration free fall.

Thus, the differential equation the process of particle sliding along a curved blade surfaces in a certain sector of angles. The rotation of the scapula is formulated. Remains to find out in which sector of the situation blades this process takes place.

2.3 Valid process sector particle slip

Expression (12) contains the initial angle φ_0 installation of the blade on the surface of which begins to slip particles of material. Obviously, with such an initial angle it is advisable to assign an angular position blades at the moment of its end point exit from an array of material as shown in (Figure 4).

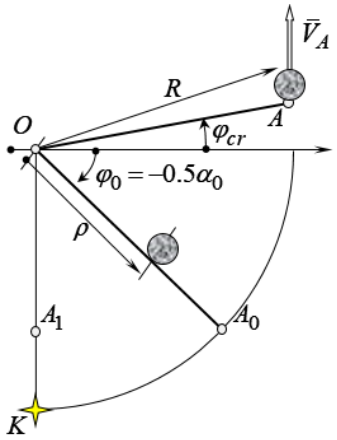

Fig. 4. Towards a process sector definition particles sliding along the surface of the scapula.

But in this case, the value of the initial angle in which begins the process of sliding particles on the surface of the blade at the accepted beginning angular position will be half of the reference angle taken with a negative sign:

$$\varphi_0 = -0.5\alpha_0 \quad (13)$$

In the process of sliding particles on the surface blades when it rotates around the axis of the rotor it is necessary to determine the maximum permissible rotation angle value φ_{cr}. This criteria the angle is determined by the safe ejection condition the last particle from the surface of the scapula. Absolute speed direction particles after its discharge from the scapula should not facilitate the fall of the particle to the surface subsequent rotor blades. Based on this conditions take the value of the criteria angle equal to zero:

$$\varphi_{cr} = 0 \quad (14)$$

Using boundary constraints (13) and (14), it becomes possible to analysis on the result of the decision differential equation (12) with the goal selection of device geometry and its modes movement. Investigation of particle slip along the surface of the blade is made for the sector blade position determined inequality:

$$\varphi_0 \le \varphi \le \varphi_{cr} \quad (15)$$

Outside the range (15), the slip process itself slow last particle over the surface the blades will be considered unacceptable.

Place on the working surface of the scapula several particles on equal radial distances from each other and analyze the process of their sliding on the surface of the blade in according to inequality (15).

Solution of the differential equation (12) we will carry out for each of the selected particles by numerical methods.

When illustrating the results, we will take into account the uniformity of rotation of the rotor with shoulder blades by law:

$$\varphi(t) = \varphi_0 + \omega_e \cdot t = \varphi_0 + \frac{V}{R} \cdot t \quad (16)$$

in the valid range:

$$-0.5\alpha_0 \le \varphi \le 0 \quad (17)$$

For calculations, we'll use the program written in accordance with equation (12) and (17). The calculation results are shown in Figure 5 for the following basic parameters:

- the number of particles on the blade in uniform radial distribution – 5;
- the outer radius of the rotor with blades is 1 m;
- the coefficient of friction the surface of the scapula is 0.4.

We accept the value of independent variables parameters:

- the speed of the conveyor belt with an array material – 10 m/s;
- coefficient of fineness of the rotor with blades (the ratio of the height of the layer of material to the outer the radius of the rotor with blades) – 0.2 (such thus, in this case, the height of the layer of material 200 mm).

The radius of the initial position of the point increases with an increase in its index. Point zero index in the initial position located in the area of the rotor hub with blades.

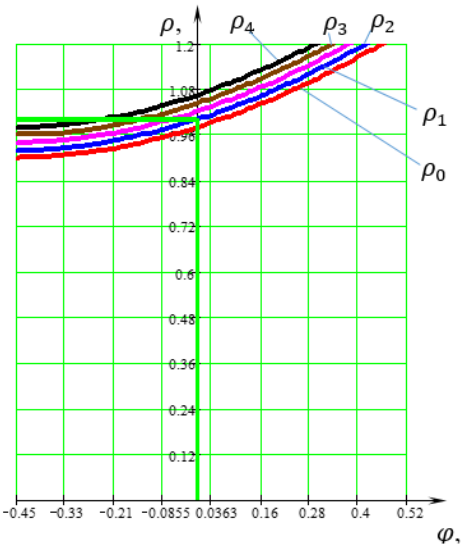

Fig. 5. The selected parameters of the variables fully support unloading.

Selected variable parameters fully support unloading the angle of rotation of the blade, corresponding condition (15) looks like a rectangle φ_{cr}, bounded by a corner to the right and a radius from above R. If upon reaching the blade criterion angle φ_{cr} is the slowest particle on the blade (with a zero index) it did not leave, those did not reach the radius R, then this means that some slow particles in the process rotor rotations with blades do not toss in the direction of movement of the conveyor.

These particles fly out in such a way that again rotor traps and fall into the entry area blades into an array of material. Thus, the criterion of appropriateness and device efficiency meets the case when all the curves leave the rectangular region without crossing its right border.

After separation of the particles of bulk material from the surface of the scapula, it starts loose flight in the air under the action of acquired kinetic energy. Separation of each particle happens at a specific time when reaching a certain the current angle of the blade (Figure 6).

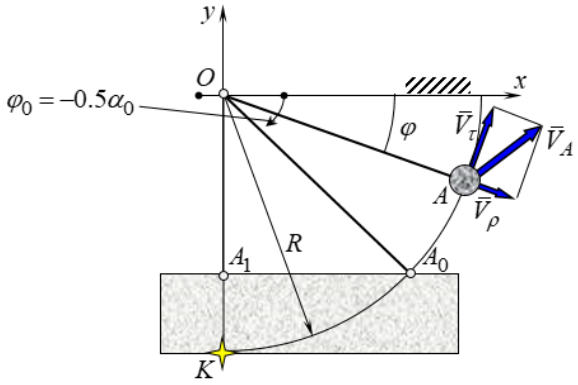

Fig. 6. On the determination of the particle velocity vector when it is separated from the scapula.

On the determination of the velocity vector particles at its separation from the scapula in accordance with the law of addition of speeds we have the vector equality:

$$\bar{V}_A = \bar{V}_\tau + \bar{V}_\rho \tag{18}$$

where $\bar{V}_A$ – is the vector of absolute particle velocity in the moment of its departure from the surface of the scapula; $\bar{V}_n$ – vector of radial particle velocity; $\bar{V}_\tau$ – vector of tangent speed particles.

Both vector terms can be calculated in its absolute value from the following ratios:

$$\left|\bar{V}_\tau\right| = V \tag{19}$$

$$\left|\bar{V}_\rho\right| = \frac{d\rho}{dt} \tag{20}$$

Expression (20) is determined on the basis of the found differential solution equations (12).

In the projection on the axis of the absolute coordinates xOy with taking into account the negativity of the angle φ, equality (18) will take the form:

$$\begin{cases} V_{Ax} = -V\sin\varphi + V_\rho\cos\varphi \\ V_{Ay} = V\cos\varphi + V_\rho\sin\varphi \end{cases} \tag{21}$$

After determining the projections of the absolute particle velocities and taking into account the angular position blades solve the differential equation movements of each particle and find for each of them the law of motion before they fall on material surface.

$$\begin{cases} x = \int V_{Ax}dt + C_x \\ y = \int V_{Ay}dt + C_y \end{cases} \tag{22}$$

Integration constants are determined by initial conditions at the initial moment time:

$$\begin{cases} x(0) = R\cdot\cos\varphi \\ y(0) = R\cdot\sin\varphi \end{cases} \tag{23}$$

The distance from the axis of the rotor to the place of impact of each particle at time T along the surface material on the conveyor is determined:

$$L = x(T) \tag{24}$$

In this case, the vertical coordinate of all the fallen particles will be the equal

$$y(T) = h - R \tag{25}$$

Thus, the definition of longitudinal surface area material moving along with the conveyor belt ribbon can be considered defined.

An example of calculating the sieving zone with the previous initial conditions of movement of the rotor and belt the conveyor is shown in Figure 7.

From the obtained dependencies and, accordingly, Figure 7 scattering parts, we can conclude that effective material excavation will depend heavily on geometric dimensions of the wheel, speed transporting material and its height to conveyor belt, as well as physical mechanical properties of the processed product characterized by a coefficient of friction slip.

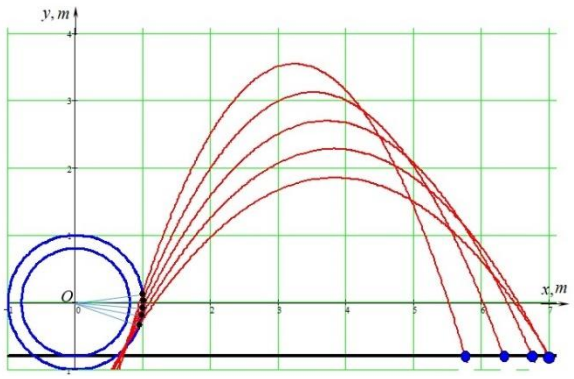

Fig. 7. Particle scattering with one blade for a given rotor.

3 Conclusion

The paper presents a mathematical model, which allows us to analyze the material's movement – "conveyor-mixer" systems and choose its rational parameters, promoting homogeneity of raw materials used in various technological metallurgical production processes.

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Sustainable development of the steel plate hot rolling technology due to energy-power process parameters justification

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Abstract. In order to ensure sustainable development of rolling production, technological processes were investigated using computer simulation, which allows us to examine a large amount of information regarding modes of reduction and energy consumption of metal treatment under pressure in order to determine rational values. Simulation of hot rolling process using DEFORM-3D software was performed to investigate energy parameters of treatment and to determine rational reduction modes. During investigation, objects were located in space, exact positioning of casting rollers respectively to workpiece was performed, and rheological model of deformable material was specified, where rigid-plastic environment was adopted. Mechanical properties of workpiece material were determined, low carbon steel was selected as material, reduction between casting rollers was specified, and friction coefficient between workpiece and rollers, which is equal to 0.3; contact interaction between casting rollers and workpiece was specified, hot rolling temperature was set to 1000°C. Finite element model of treated material was developed, displacement in deformation zone during hot rolling and vector field of metal movement were determined. Changes in force during treatment, deformation stress during rolling were determined. Changes of rolling force in deformation zone in course of time were determined. Distribution of active stress in deformation zone was investigated. Investigations allowed us to determine energy consumption of rolling process depending on reduction modes, which provided rational treatment modes.

1 Introduction

In recent years, scientists of the Ferrous metals metallurgy and foundry Department of Kryvyi Rih National University have studied such important and relevant areas: the impact of the electric field on the steel and cast iron structure during the pouring of the alloy into the mold: the study of processes in the deformation zones during the longitudinal rolling of steel billets.

Sustainable development of steelmaking production is impossible without detailed research and improvement of technological processes of rolling, which require high energy consumption. Recently, active development of informational technologies has made possible their widespread usage in development of metal treatment under pressure processes, which allows to solve problem of increasing of rolling production efficiency and ensure production of competitive products with required quality and with minimal energy consumption. Task to improve rolling technology using rational reduction modes, which provide required quality of products with minimum energy consumption is relevant. For this purpose, it is necessary to carry out research of metal treatment using DEFORM 3D computer software, which significantly speeds up treatment process improvement.

2 Literature review and problem definition

Development of technological processes of metal treatment under pressure processes to ensure sustainable development of industry and society requires solving of large number of complex problems. Main purpose of development and improving of rolling technologies is to identify regularities of process, significant factors and parameters that affect its quality, to evaluate possible effect of reduction parameters to operational properties of produced products, to energy consumption during production [1, 2]. During rolling process, deformation zone is formed, which in is given much attention in theory of metal treatment under pressure because complex deformation processes take place in it, which further affect product quality and energy consumption of process. Investigations have shown that complex stress-strained state [3, 4] appears in deformation zone, which shall be taken into account during designing and improvement of technological processes, which is very difficult to investigate in manufacturing environment. During investigation of reduction processes using computer program, obtained data allowed us to develop informational field of technological processes of rolling, and thus provides ability to control both process and

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properties of products. Computer simulation provides opportunity to obtain large amount of information, to conduct comprehensive investigation of rolling process, to determine its features, to consider and to compare large number of alternative technological processes. Currently, analytical energy method of power balance and finite elements analysis have been acquired to investigate bulk deformation processes during metal treatment under pressure. A lot of investigations were executed regarding defect formation problem during pressing using finite elements analysis [5, 6], but it shall be noted that hot rolling process of thick sheets is not investigated in this work. Currently, promising results are given by simulation modeling of bulk deformation processes using finite elements analysis [7], which is most common numerical method for solving technological tasks.

Computer software DEFORM 3D, which is designed to analyze complex three-dimensional processes of plastic deformation of metal while its reduction, has great potential in this respect. This program is finite element simulation system [1, 8] and one of leading design-grid methods that can be finally adapted to plastic deformation tasks solving. Simulation of rolling processes using DEFORM 3D has developed more rational technologies with significantly reduced time for their design [8]. Software [9, 10] was used for research of sheets hot rolling for analysis of three-dimensional metal flow during treatment, nature of metal forming was predicted, microstructure of products was obtained, deformation force was minimized, number of transformations was optimized, but energy consumption for process was not determined.

Therefore, there is reason to believe that insufficient attention is paid to distribution of rolling force and energy consumption for process during hot rolling simulating of thick sheets using DEFORM 3D.

3 Purpose and tasks of research

Purpose of this work is to investigate energypower parameters of hot-rolling process of thick sheets, using computer software DEFORM 3D for simulation, which will provide evaluation of rational treatment modes.

To achieve this goal, following tasks were set:
- to analyze possibilities of using finite elements analysis for studying processes of metal treatment under pressure;
- to develop model of hot rolling to study effect of rolling force on physical and mechanical characteristics of treated material;
- to determine energy consumption and rational reduction modes during process of hot rolling of thick sheets.

4 Data and methods

4.1 Initial data for investigation of hot rolling of thick sheets

Technology of thick strips production by hot rolling was used to determine rational technological parameters that will ensure sustainable development of industry. Initial data for simulation [11]: dimensions of initial billet – height h_0 varied from 300 to 500 mm; width b_0 remained constant and equaled 1000 mm; length l_0 = 1000 mm; Δh of their reduction varied from 30 to 100 mm; initial rolling speed υ_0 varied from 3 to 10 m/s; radius of rollers RB = 400. Rolling temperature was 1000°C. Low carbon steel was used as treated material.

4.2 Methodology of investigation of energypower parameters of thick sheets hot rolling

Model of hot rolling of thick sheets using computer software DEFORM 3D was built to determine rational reduction modes.

During simulation Perzyna's model was used [10]:

$$\dot{\bar{\varepsilon}}=\gamma(\dot{\varepsilon}/S-1)^m, \quad (1)$$

where γ – fluidity; $\dot{\varepsilon}$ – effective stress; S – flow stress; m – material parameter; $\dot{\bar{\varepsilon}}$ – effective strain rate.

In this method creep will not occur until effective stress exceeds the yield strength of material. If effective stress is less than the flow stress, the resulting strain rate is zero.

Yield strength of material was set according to energy law [10]:

$$\sigma=\varepsilon^n \cdot u^m+y, \quad (2)$$

where σ is effective stress of plastic material flow, ε is material deformation, u is material deformation speed; n is deformation degree indicator, m is indicator of deformation degree speed, and y is material constant.

Deformation process was studied at the beginning of rolling process: with help of computer program, objects were placed in space, distance between rollers was determined taking into account dimensions of workpiece and reduction value (Fig. 1), and rheological model of deformable material was identified, where rigid-plastic environment was adopted. While simulation, flexible model was used for workpiece, and rigid material model was selected for rollers. Behavior of workpiece material was described using diagram "Stress-Strain". Mechanical properties of workpiece material were determined, low carbon steel was selected as material, reduction between rollers was specified, and coefficient of friction between workpiece and rollers is equal to 0.3; contact interaction between roller and workpiece was specified, hot rolling temperature was set to 1000°C, deformation speed, identified at the beginning of treatment, was 3 mm/s.

Deformation process was divided by 90 steps.

Number of steps was determined from formulas [9, 10]:

$$n = x/(\upsilon\Delta t), \quad (3)$$

where n is number of steps, x is summary movement of main roller, υ – main roller speed, Δt is time increment for one step.

In order to divide workpiece into finite elements, grid was generated where 80,000 elements were specified (Fig. 2). Automatic grid generation mode was used during investigation.

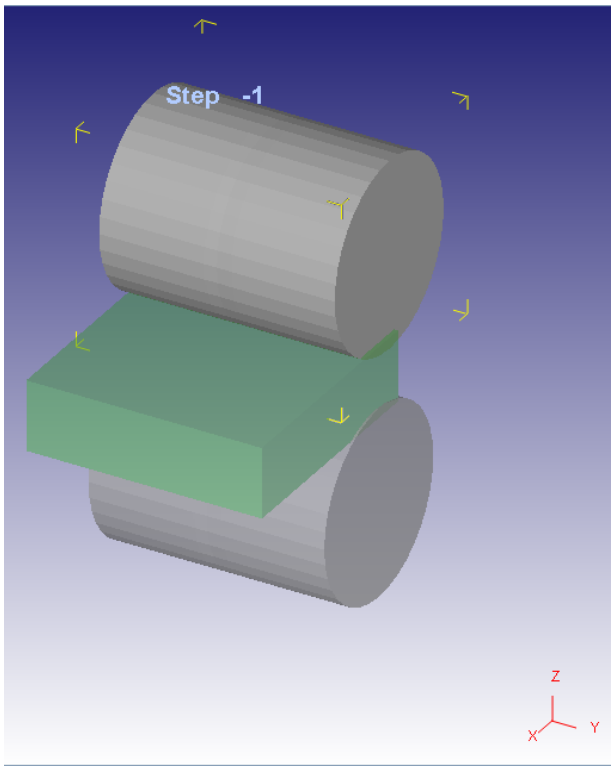


Fig. 1. Scheme of rollers and treated material location.

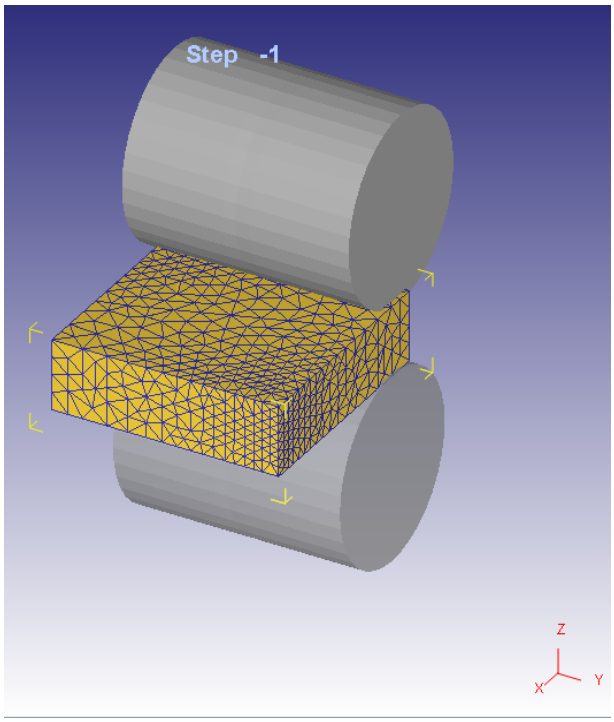
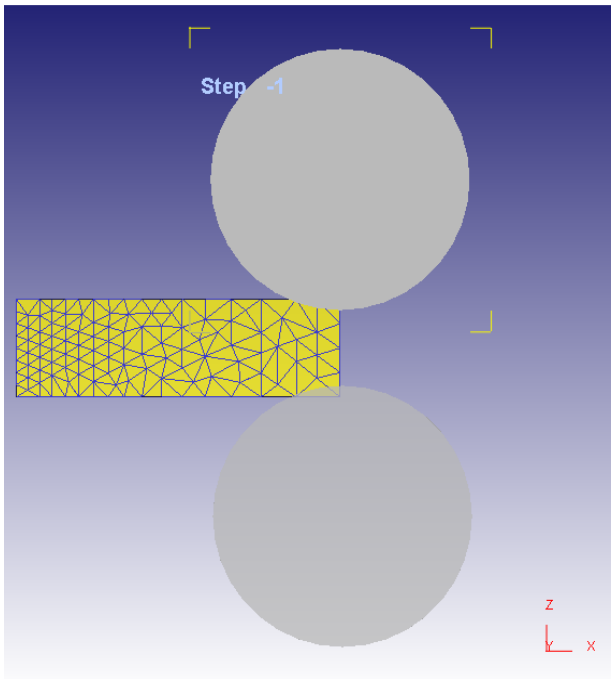


Fig. 2. Finite element model of treated material.

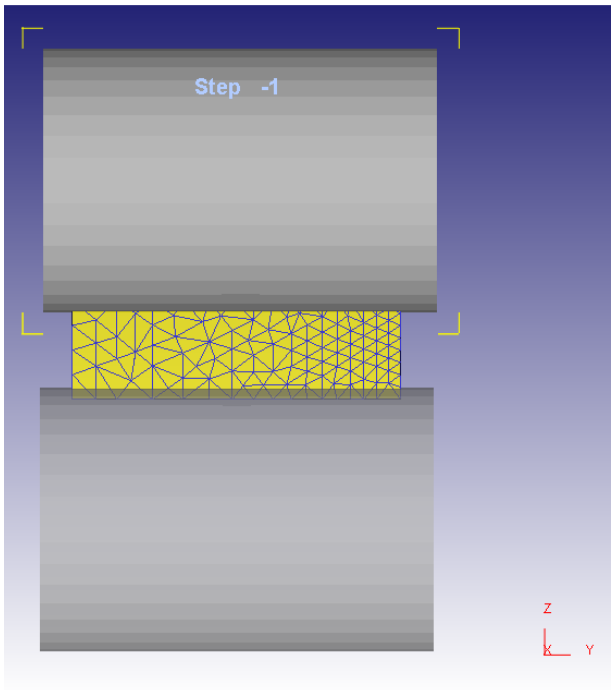
Scheme (Fig. 2) shows that during simulation process, workpiece having 1.37x103 points and 5.62x103 elements was obtained.

For exact location of objects, mutual positioning of rollers and workpiece was performed, as shown in Fig. 3, a and b, where continuous interaction of rollers and workpiece side and back is observed.

Material of treated workpiece was determined from computer software library. AISI-1015_(20-1200C) carbon steel material was used for investigation. The properties of the material are learned in many ways. Material is easy to deform. The material has elastic and plastic properties.



a



b

Fig. 3. Positioning of objects: a) side view; b) back view.

Elastic properties of material were determined (Young's modulus and Poisson's ratio), which equal to 0.3 and $1.5 \cdot 10^5$ accordingly, which are constant values. Diagram "Flow Stress-Strain" is presented in Fig. 4, which shows that if strain during reduction increases, flow stress increases as well.

Parameter "Strain" shows degree of workpiece relative reduction, which is determined according to

formula [11]:

$$\varepsilon=\Delta h/h_0, \quad (4)$$

where Δh is absolute reduction,

$$\Delta h = h_0 - h_1 \quad (5)$$

where h_0, h_1 – initial and final thickness of strip accordingly.

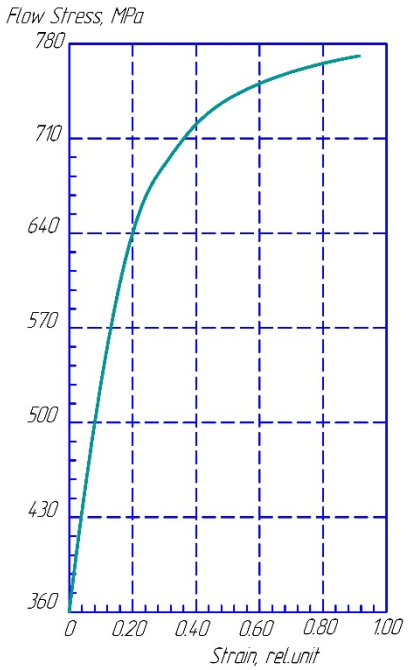


Fig. 4. Diagram "Flow Stress-Strain".

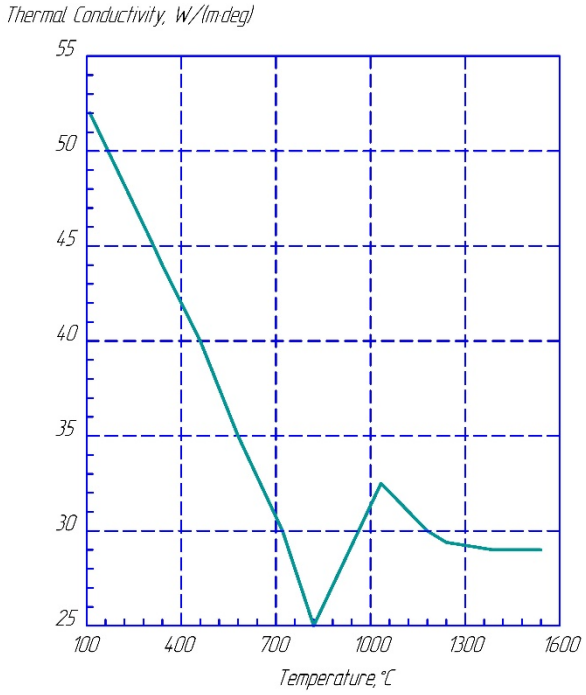


Fig. 5. Thermal conductivity depending on temperature.

Thermal conductivity of material, and its dependence on temperature is shown in Fig. 5, where it is shown that with increasing temperature, thermal conductivity decreases until temperature reaches 800°C. During further heating thermal conductivity increases until temperature reaches 1000°C, after this temperature thermal conductivity decreases again. So, treatment is carried out under conditions of maximum thermal conductivity.

Heat capacity of investigated material, which depends on treatment temperature, was determined (Fig. 6). Graph shows that heat capacity of treated steel at temperature of 700°C takes maximum values. At treatment temperature of 1000°C, heat capacity decreases.

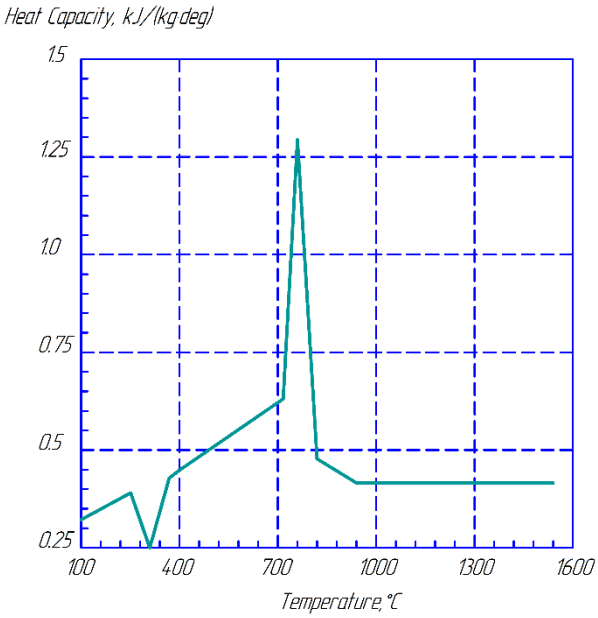


Fig. 6. Dependence of heat capacity of steel on temperature.

Thus, model of hot rolling of thick sheets was constructed to investigate processes occurring in deformation zone.

5 Results of investigation of energypower parameters of hot rolling of thick sheets

Investigation of deformation distribution in treated material enabled to identify its displacement during reduction (Fig. 7). Figure shows distance of displacement and its distribution in deformation zone.

Material flow along curvature of coordinate grid can be seen on Fig. 8, which shows that maximum deviation from original location occurred in center of deformation zone with upper layers.

Vector field of metal displacement during deformation was investigated (Fig. 9), which shows metal movement direction during reduction and displacement of grid points. During simulation process, graph of deformation force change in course of time is made, where it can be seen that force increases from zero to 6.68 MPa during first 27 s. After this, force slowly increases to 8.35 MPa and displacement of metal varies from 1.34 to 25.2 mm.

During simulation process, graph of deformation force change in course of time is made, where it can be seen that force increases from zero to 6.68 MPa during first 27 s.

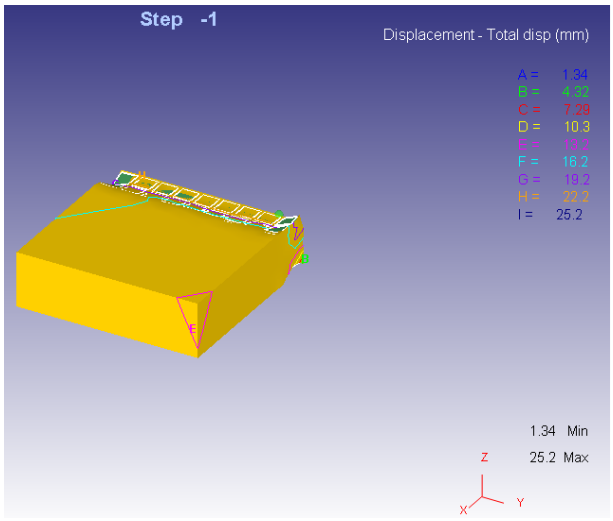


Fig. 7. Metal displacement in deformation zone during reduction.

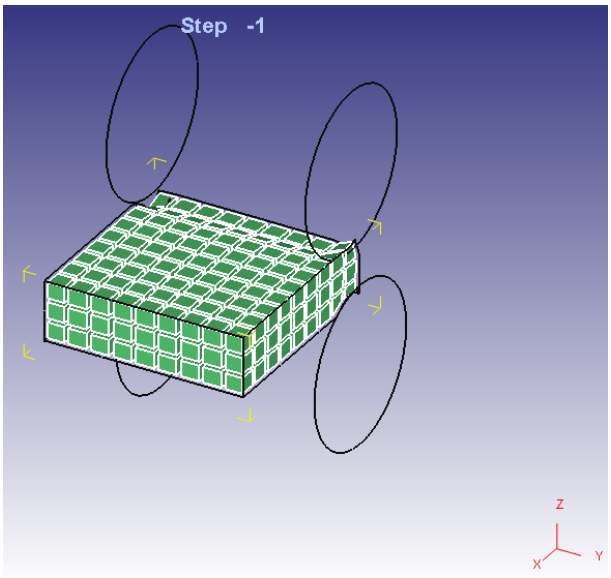


Fig. 8. Coordinate grid of billet.

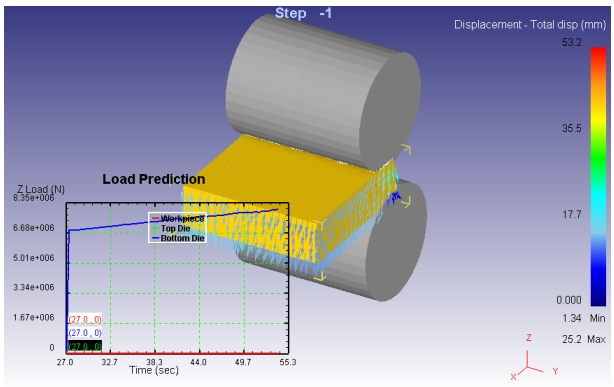


Fig. 9. Vector field of metal displacement during deformation.

After this, force slowly increases to 8.35 MPa and displacement of metal varies from 1.34 to 25.2 mm.

Figure 10 shows graph of change of force applied on roller at initial rolling moment, where it can be seen that force applied on roller varies from 0 to 4.1 MN and displacement fields apply up to 27 mm. Under real conditions for these modes, rolling force reached 4.4 MN [11], which corresponds to high simulation accuracy, where error is 6%.

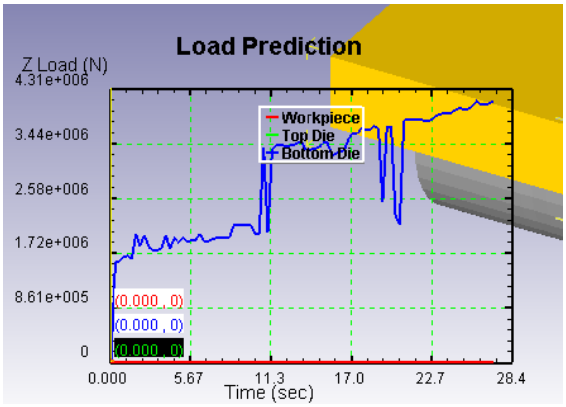


Fig. 10. Change of force applied on roller.

During treatment under pressure, treated material is subjected to non-uniform stress that causes non-uniform plastic deformation. It is determined that both circumferential and normal stress occur during rolling.

Change of stress during deformation was investigated (Fig. 11). It is found out that during hot rolling, large reduction, which reaches more than 10 mm, reduce effect of stress non-uniformity on product quality.

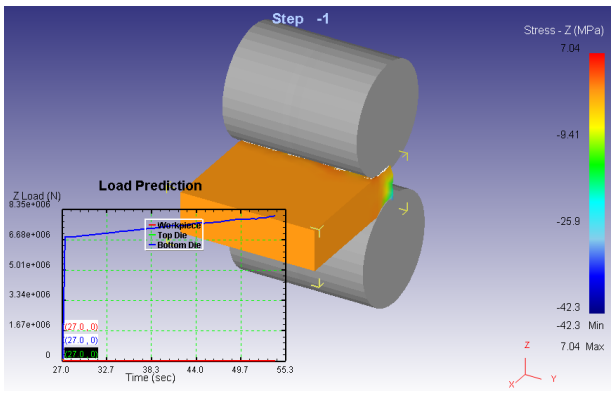


Fig. 11. Change of stress during deformation.

Distribution of acting stress according to its value is shown in Fig. 12, where it is seen that its value in deformation zone reaches 37 MPa and decreases with decreasing reduction value.

6 Discussion of energypower parameters investigation results and identification of rational reduction modes

Thus, deformation and energy parameters of hot rolling were investigated by finite element simulation of processes in DEFORM 3D complex. Developed model takes into account direction of metal displacement during rolling, change of force during reduction in deformation zone, distribution of acting stress and its change. Such investigations allowed to develop technological scheme which usage enables to increase accuracy and to improve

internal structure of metal products at rational energy consumption.

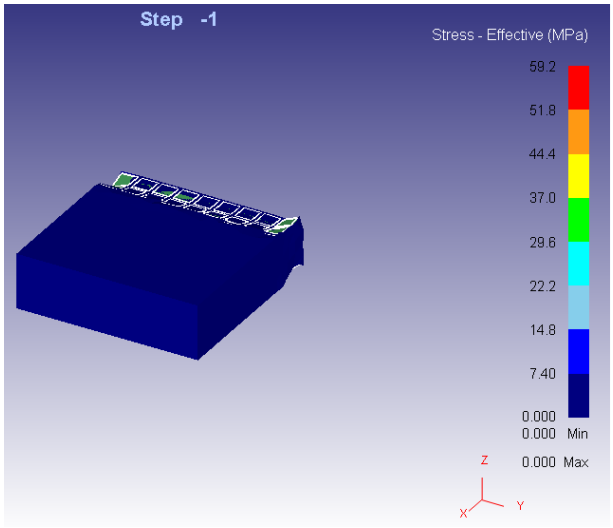


Fig. 12. Distribution of acting stress in deformation zone.

Investigations enabled to identify energy consumption for rolling process depending on reduction modes, what enabled rational treatment modes.

Energy consumption includes kinetic energy of rolled workpiece, potential energy in deformation zone for surface tension formation and metal strengthening, strain energy and energy for metal heating [11].

Kinetic energy of rolled workpiece was determined according to formula [11]:

$$E_k=0{,}5\rho b_1 h_1 \upsilon_1^3, \quad (6)$$

where υ_1 – roller speed; b_1 – width of strip after rolling; ρ – steel density, ρ = 6860 kg/m^3.

Potential energy consumption in deformation zone for surface tension formation and metal strengthening are determined according to formula:

$$E_p=2b_1 h_1 \upsilon_1 \sigma_{st}+V\sigma_T/\tau, \quad (7)$$

where V – deformation zone volume; m^3; σ_{st} – surface tension; τ – duration of metal being in deformation zone; σ_T – yield strength.

Strain energy:

$$A=\sigma_T(\varepsilon_h+\varepsilon_b+\varepsilon_l)h_1 b_1 R/\tau, \quad (8)$$

where R – rollers radius, ε_h; ε_b; ε_l – relative deformation of sheet during reduction, broadening and elongation.

Energy consumption per unit of time for heating of rolled products

$$Q= V\sigma_T i/\tau, \quad (9)$$

where i – heat capacity.

To determine total energy consumption per unit of time, sum of listed items was calculated.

$$W= E_k+ E_p+ A+Q \quad (11)$$

Investigation results are shown in Table 1.

Table 1. Energy-power parameters of hot rolling process.

h_0, mm	h_1, mm	b_1, mm	υ_1, m/s	W, kJ/s
300	255	1150	5,12	878474,2
500	400	1200	3,2	10144297

Such investigations enabled to use rational reduction modes (Table 1) during development of technological process of thick sheets manufacturing by hot rolling, which ensures sustainable development of rolling technologies.

7 Conclusions

During execution of investigation on hot rolling process of thick sheets, following results were obtained:

- opportunity to use finite elements analysis for investigation on processes of metal treatment under pressure was analyzed, that enabled execution of investigation on hot rolling process of thick sheets using computer software DEFORM 3D;
- model of hot rolling process that enables to investigate physical and mechanical processes in deformation zone, which occur during metal treatment under pressure was developed;
- deformation force and its distribution in deformation zone were identified; energy consumption and rational reduction modes during hot rolling of thick sheets that enable manufacturing of high-quality products were specified;
- it is suggested to use rolling modes adopted in Table 1 during manufacture of thick sheets to save 6-8% of energy during plate rolling

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Analysis and synthesis of factors determining the sintering speed of sinter charge

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Abstract. The main objectives of the study are the analysis and generalization of the parameters that determine the intensity of the sintering, the development of a model of motion of the combustion zone of the sinter charge. As a result of the analysis of the known indicators of the intensity of the sintering process, it was shown that the most representative characteristic of the intensity of the process is the vertical sintering speed, which is an integral part of the complex intensity indicator − the specific productivity of the sintering machine. Many various models of the sintering process have been developed. The author develops a new mathematical model of the motion of the solid fuel combustion zone during sintering of the sinter charge (vertical sintering speed). The model is presented in the form of an expanding network of separate interrelated dependencies (equations), selected as independent submodels. The results of the study using the developed model of the dependence of the vertical sintering speed on the solid fuel content and on the flux content in the charge, are presented. It is concluded that the presented model can be considered as an element of a universal model software complex of the sintering process.

1 Introduction

At the present stage of development of ferrous metallurgy, sinter is and will remain for a long time the main type of prepared iron ore for the production of pig iron and pig iron, in turn, is the main source material for steel production. Therefore, issues related to improving the efficiency of sinter production are of undoubted practical and scientific interest, are one of the conditions for ensuring a sustainable future for the steel industry. One of the urgent problems of scientific and technological progress in sintering production is to increase its intensity, which means increasing the intensity of the technological process, increasing its speed.

Despite the presence of a rather large number of monographs, articles, scientific and technical conferences devoted to the intensification of the sintering process [1-3], methods for assessing and indicators of the intensity of the sintering process are not well understood. To date, a detailed analysis of the used indicators of the intensity of the sintering has not been performed, the relationships between them have not been studied, as is done, for example, with respect to the indicators of the intensity of the blast furnace. This situation negatively affects the development of sintering production, since it does not allow a reliable comparison of the intensity of the sintering machines, the sintering rate of sinter charge as well as the development effectiveness of various methods of intensifying the sintering process of the iron ore charge, and the assessment of the reserves for improving the technical and economic indicators of the operation of sinter plants. Since the determining technological operation in the production of sinter is the sintering of the sinter charge, it is precisely on it, in the first place, attention should be paid to solving this problem. This article is devoted to the analytical study and generalization of indicators of the intensity of the sinter process, factors affecting the of a new mathematical model, the movement of the combustion zone of solid fuel of the sinter mixture and its application to assess the influence of various factors on the sintering.

2 Literature review

The analysis of indicators of the intensity of the sintering process should begin with the term “intensity of the sintering process” proposed by H. Wendeborne in 1934. It is defined as the ratio of the total heat consumption for heating a material to the amount of heat released during the combustion of carbon in CO and CO_2 and during exothermic reactions, minus the heat for oxide dissociation and evaporation water, the value of which is close to 1.9-2.1, is essentially a thermal characteristic of the sintering process, depending on the composition of the charge. This indicator is not related to the speed of the sintering process and is not used to assess the intensity of the sintering process.

As a rule [4, p. 50; 5, p. 345], the sinter process intensity (sinter machine operation intensity) is estimated using two indicators: 1) specific sinter productivity, measured in tons of suitable sinter, produced from 1 m^2 of sintering area of the sinter machine in the “hot” hour (that is, without taking into account the downtime of the sinter

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machine); 2) the vertical sintering speed, measured by the length of the path traveled by the combustion zone of solid fuel per unit time.

A feature of the sintering process, which must be taken into account when assessing its intensity, is the complex nature of the process, which includes three successive technological stages: 1) preparation of the charge for sintering; 2) sintering of the charge; 3) crushing sinter and separation of the return. Each of the stages has both a direct effect on the intensity of the sintering process, and indirectly − through the impact on the subsequent technological stages of sinter production. Based on these considerations, the specific productivity of the sinter machine is a comprehensive indicator of the overall intensity of the sintering process, since all the above stages of the technology of sintering production find expression in it. It is also obvious that the vertical sintering speed directly characterizes only the second stage of the sintering technology and should be considered as one of the components of the overall intensity of the sintering process. The two other components that determine the overall sintering intensity should be considered the bulk mass of the charge and the yield of suitable sinter from the charge, which directly characterize the first and third stages of sintering − preparation of the charge for sintering, crushing of sinter and separation from it the return respectively.

We derive a formula relating the general indicator of the intensity of the agglomeration and the private (its components) indicators of intensity. To do this, we will use the following notation: q_s − specific productivity of the sinter process according to suitable sinter, kg/(m^2 s); ρ − bulk density of the charge, kg/m^3; v − vertical sintering speed, m/s; k− yield of suitable sinter from the charge, a fraction of units; then the general indicator of intensity will be a product of its three private components:

$$q_s = \rho \cdot v \cdot k. \quad (1)$$

Comparison of the three components of the total (complex) indicator of the intensity sintering shows that the most significant and important of them is the vertical sintering speed. The predominant role of the vertical sintering rate in the overall intensity of the sinter process is due to at least three circumstances. Firstly, it is the only component of the general intensity, which has a unit of time in its dimension, without which the concept of intensity loses its physical meaning. Secondly, the practical possibility of sintering intensification is associated, first of all, with an increase in the vertical sintering speed, which in real conditions of sintering production varies widely. The increase in the intensity of the sinter process due to two other components is in most cases limited by the relatively insignificant effect of the composition of the initial charge materials on the bulk density of the charge, as well as the requirements for the quality of the finished sinter. Thirdly, the vertical sintering speed characterizes the process of burning solid fuel of sinter charge, which is the cause of the formation of the melt, which actually ensures the sintering of the charge during the sintering process.

Given the importance of the indicator of the vertical sintering speed of the sinter charge, the practical and theoretical interest is the problem of its calculation definition, for the solution of which today there is no reliable generally accepted technique.

With sufficient accuracy for engineering calculations proposed [6, p. 496] assume that

$$v_s = w_o/(V_g \cdot \rho), \quad (2)$$

where v_c – vertical sintering speed, m/s;
w_o – gas filtration rate in the layer, m/s;
V_g – specific yield of sinter gas, m^3/kg dry charge;
ρ − bulk mass of the sinter charge, kg/m^3.

At the same time, it is known [6, p. 507] that the vertical sintering speed is directly proportional to the gas permeability of the sintered layer R, m^3/m^2 min, the heat capacity of gases c_g and inversely proportional to the apparent heat capacity of the charge $c_{ap.ch.}$:

$$v_s = k\,(c_g/c_{ap.ch.})\,R, \quad (3)$$

where k − coefficient of proportionality.

Comparative calculations have established that formula (2) has the greatest versatility and suitability for practical use. Formula (3) is less preferable for the calculated determination of the vertical sintering speed due to the difficulty of accurately taking into account all the factors affecting the apparent heat capacity of the charge and the ambiguity of its determination methods. Moreover, comparing formulas (2) and (3), it should be borne in mind that in the region of a high carbon content in the charge (more than 4%), despite the decrease in the apparent heat capacity of the charge due to an increase in the mass fraction of carbon in it, the sintering rate decreases [5, p. 170], although according to formula (3) it should increase.

Another indicator characterizing the intensity of sintering of the charge may be the residence time of the charge on the sinter machine (more precisely, over the sintering area of the sinter machine). If we denote the height of the sintering layer of the mixture through H (m), then in the normal course of the sinter machine, the residence time of the charge on it is determined by the formula

$$\tau = H/v. \quad (4)$$

Substituting into the formula (1) instead of the vertical sintering speed its value from formula (4), we obtain a slightly different, more convenient for practical use form of the formula for calculating the specific productivity

$$q_s = \rho \cdot H \cdot k/\tau. \quad (5)$$

The main method of theoretical generalization of factors influencing any process is mathematical modeling, which is widely used in various fields, including in the process of agglomeration. Modeling of sintering and firing processes should contain a combination of the most important properties inherent in the objects of study. When constructing models of sintering and firing, it is necessary to take into account the numerous parameters of this process [7]. Important input parameters are: the

content of the main components in the charge; charge moisture; gas permeability of the charge; charge layer height; air consumption for the process; ignition conditions – hearth temperature (temperature in the space of furnace), ignition temperature (temperature above the surface of the sintered charge), generalized heat treatment temperature. Important output parameters are: sintering speed; composition and temperature of exhaust gases; mass fraction of iron oxide in the finished product; discharge; sintering time. Disturbing effects: change in the composition of the charge; change in the moisture content of the charge; change in the degree of compaction of the charge; change in the height of the charge layer; change in the speed of movement of the sinter; suction of cold air; change in discharge above the ignited layer; change in the fuel-air ratio.

Currently, computer simulation has become widespread, making it possible to process large amounts of information as part of control systems for complex metallurgical processes, which is sinter production. It is believed [8] that the combination of a mathematical model and artificial intelligence is a suitable method for controlling the sintering process.

Deficiencies and limitations of existing mathematical models for determining the performance of sintering machines were identified [9]. These disadvantages depend on a number of technological factors, often interrelated: the speed of movement of the trolleys of the sintering machine, the vertical speed of sintering of the charge, the speed of filtration of air in the layer of the sinter charge. Based on the identified shortcomings and limitations of the existing mathematical models for calculating the performance of sintering machines, the following basic set of technological factors was proposed to develop a mathematical description of the dependence of the performance of the sintering machine on the parameters of the sintering process: general gas-dynamic resistance of the charge layer; the height of the charge layer on the sinter machine; bulk density of the sinter charge; particle size distribution of the sinter charge (the size of the sintered material expressed in terms of the equivalent diameter of the pelletized charge); the duration of the sintering of the charge; sinter charge temperature; sinter charge moisture; return share/yield; carbon content in the sinter charge; the content of fine-grained concentrates in the sinter charge.

A study of the performance indicators of the agglomeration process [10] showed that in laboratory conditions the most objective is a comparative assessment of the productivity of the sinter process by raw charge and yield of sinter with a closed balanced cycle of the return of the constant size. Under production conditions, it is advisable to conduct a comparative assessment of the specific productivity of the sinter process taking into account the total yield of the return or the strength of the sinter.

Based on the characteristics of the sintering process, a long and short term control strategy of sintering burn through point was put forward [11], with the burn through point optimized with a fuzzy controller. Long term control was realized by adjusting bed height or density according to the state of preignition permeability and vertical sintering speed. The rising position of gas temperature was stabilized by adjustment of pallet speed, enabling short term control to be carried out. By using vertical sintering speed to represent bed permeability a prediction model of vertical sintering speed was established. The predicted results are in accordance with calculated values and accuracy of the model is >95 %. The application of system shows that the accuracy of guidance is >95 % and this system can be used to industry production.

Using the dimensional analysis method, formulas (models) for the efficiency of the sintering process (specific productivity of the sintering machine) were developed from: 1) the gas permeability of the charge; 2) the size of the charge; 3) a specific load complex equal to the product of the height of the charge layer by the bulk density of the charge; 4) vertical sintering speed [12]. These formulas allow us to calculate the optimal process parameters for specific charge conditions of the sintering process.

The above analysis shows that the intensity of the sintering process (vertical sintering speed) is determined by a combination of factors forming the material composition and structural and gas-dynamic characteristics of the sintered charge layer. Based on this approach, we will carry out mathematical modeling of the process of moving the combustion zone of solid fuel in the sintered layer, taking as a basis formula (2), as the most versatile and suitable for practical use.

3 Problem formulation

Based on the foregoing material, the following tasks were set in the work. To develop a new model of the movement of the combustion zone of solid fuel of the sinter charge, characterizing the intensity of the sintering process, and also discuss the possibilities of its application to assess the influence of various factors on the sintering intensity.

4 Methods

The following methods were used to solve the tasks:
- scientific analysis and generalization of previously performed studies of agglomeration production aimed at determining the factors that determine the sintering rate of the sintering charge;
- theoretical studies of the influence of individual factors that affect the sintering rate of the sintering charge;
- experimental studies of technological techniques what determines the speed of the combustion zone of solid fuel;
- mathematical modeling of the process of moving the combustion zone in the sintering layer.

5 Analysis

The development of a model for moving the fuel combustion zone in the charge began with the formalization of this process. At the same time, a number of interrelated physical and chemical processes and gas-dynamic phenomena were taken into account when preparing the charge for sintering and directly during

sintering of the sintering charge layer, namely: the formation of the bulk mass of the pelletized charge; gas movement in the sinter layer; burning carbon solid fuel; dissociation of carbonates; the change in gas volume along the height of the sintered layer as a result of heat and mass transfer processes.

The main structural elements of the model are charge parameters and gas parameters that characterize the initial state of the system.

The parameters of the sinter charge, characterizing the initial state of the system, include: the content of the individual components of the charge; mass fraction of carbon in fuel, CaO in limestone and CaO_{act} in lime; fractional composition of fuel and charge; charge layer height.

The input gas parameters established during the calculations for a specific case of sintering are: the composition of the gas at the entrance to the layer; air suction rate through the sinter layer; specific air consumption for sintering.

The processes under consideration are grouped into the following subsystems: gas filtration rates in the layer; specific output of sinter gas; bulk density of the pelletized charge.

The output parameter is the vertical sintering speed of the sinter charge.

Thus, the structural diagram of a mathematical model can be represented in the form of Figure 1.

Having designated the main structural elements of the model, we will carry out the development and idealization of its mathematical description.

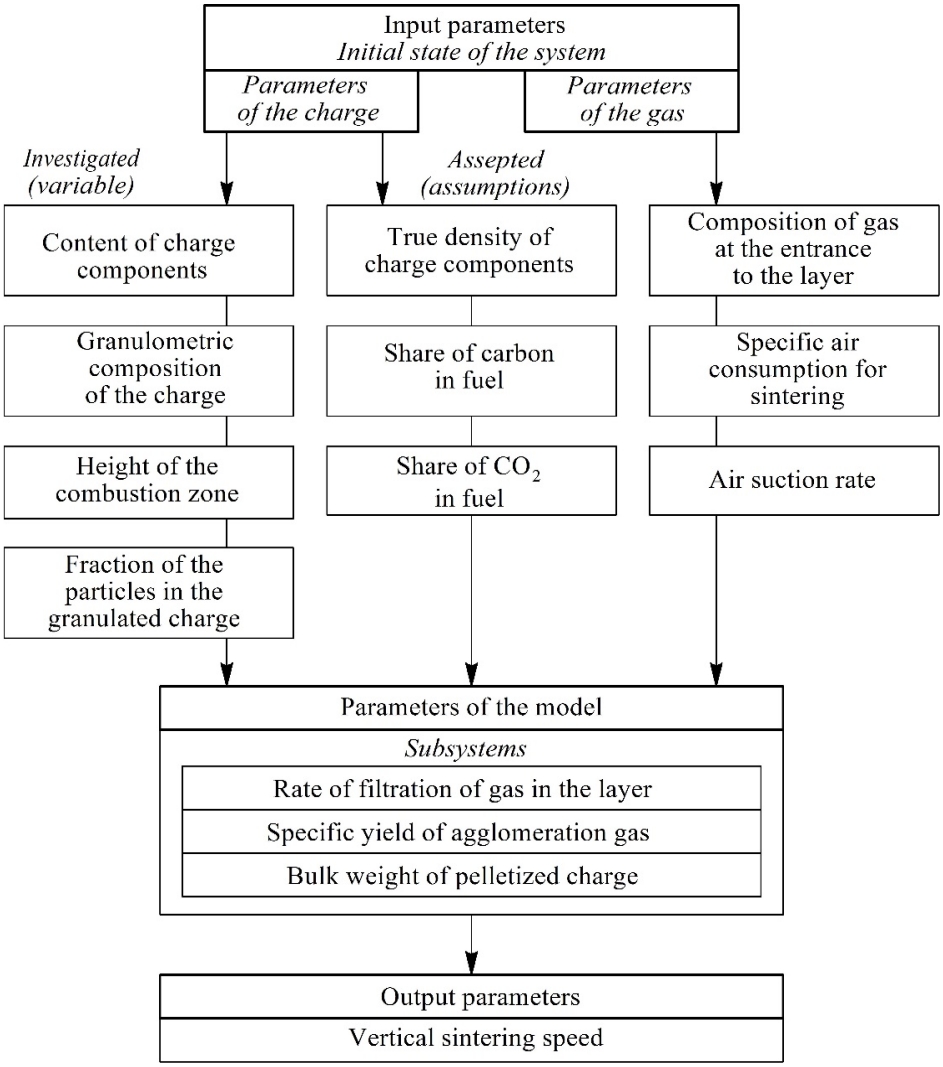

Fig. 1. Structural scheme of mathematical model of movement of the combustion zone solid fuel in the sintering layer of the charge (vertical sintering speed).

In developing the mathematical description of the conceptual model of the vertical sintering speed, the following basic assumptions were made:

1) the charge is presented in the form of ore, fuel, flux particles and the return of spherical shape;

2) carbon burning occurs according to the reactions $C + 0{,}5O_2 = CO$, $C + O_2 = CO_2$;

3) the granulometric composition of the pelletized charge is determined by the mass fraction of individual fractions of fineness in the initial charge and the content of binder additives under optimal pelletizing conditions;

4) the gas flow is evenly distributed over the cross section of the layer, and its flow rate over time is unchanged;

5) heat loss to the environment is negligible;

6) the rate of combustion of a fuel particle is determined by its size and true density;

7) the fuel burns in a layer of inert materials and its particles are equidistant from each other.

When developing submodels for determining the gas filtration rate, the following assumptions were made:
- the specific air consumption for sintering the non-fluxed charge from hematite ores and magnetite concentrates is 0.35-0.40 m^3/kg (in the practice of sintering of iron ore materials in most cases the carbon content does not exceed 5% and the specific air consumption remains almost the same [5, p. 111]). This assumption was made when calculating the specific yield of sinter gas (based on typical air flow);
- the height of the combustion zone for typical sintering conditions (fuel with a size of 0-3 mm) is 1/10 of the total height of the sintered layer [5, p. 65, 68];
- the rate of gas leakage through the sinter layer is 0.35 m/s. These assumptions were made when calculating the dependence of the burning rate of fuel particles on various factors.

The sinter gas specific output subsystem takes into account the flow of carbon into the charge with fuel and limestone, as well as the characteristics of the gas entering the layer.

When developing the formula for the mathematical description of the specific output of the sintering gas, the following assumption was made: the parameters of the air supplied to the layer correspond to atmospheric at a temperature of 25 °C, which is typical for typical sintering conditions.

The bulk density subsystem of the pelletized charge takes into account the characteristics of the charge (chemical and particle size distribution), as well as the fines content in the charge and the ratio of the diameters of small and large particles.

When developing a submodel of the bulk density of the charge, the following assumptions were made:
- the density of the components of the charge is unchanged;
- during pelletizing, the number of relatively large granules increases as a result of rolling a small fraction onto the embryos.

The mathematical model of the movement of the combustion zone in the sintered layer is presented in the form of an expanding network of separate interrelated dependencies (equations), identified as independent submodels.

We set the range of input data for typical sintering conditions:
- the height of the sintered layer does not exceed 500 mm;
- the size of solid fuel (coke breeze) does not exceed 5 mm.
- the chemical composition of the mixture has a number of limitations on the input data on the content of limestone and solid fuel. The limestone content should be in the range from 0 to 25 %, since the nature of the curve of the temperature change of the air entering the combustion zone with a high content of fluxing additives has not been fully studied. The content of solid fuel (coke breeze) should not exceed 8 %, since some mathematical dependencies expressed in the corresponding submodels will be unfair;
- the density of the components of the charge and air parameters are taken according to the reference data. The density of the charge components (kg/m^3): magnetite concentrate 4.7; hematite ore 4.5; coke breeze 1.6; limestone 1.0; dolomitic limestone 1.1; lime 2.0; refund 3.5; manganese ore 4.2.

The adequacy check and adaptation of the model for determining the vertical rate of sintering of the charge was carried out by comparing the simulation results with experimental data obtained in laboratory and industrial studies conducted at the sinter plant of MPP of PJSC "ArcelorMittal Kryvyi Rih" – mining and processing plant of public joint stock company "ArcelorMittal Kryvyi Rih".

The research was carried out in the laboratory. The ore part of the charge consisted of MPP concentrate (90 %) and Kryvyi Rih agglomeration ore (10 %). For fluxing, a mixture of ordinary and dolomite limestone in a ratio of 3 : 2 and quicklime obtained by firing this mixture of limestones was used. The degree of calcination of limestone was 70 %, the size-3-0 mm. As a solid fuel, a mixture of coke and anthracite block in a ratio of 1 : 1 was used. The content of fuel, return and additional manganese ore in the charge was 4, 18 and 2 %, respectively. The height of the sintered layer was 0.28 m, the charge basicity was 1.3.

The calculation of the numerical methods of the model was carried out using the Microsoft Excel software application. According to the experimental data, the vertical sintering speed for a charge with such parameters is 26 mm/min., and according to the results of calculations using the model it is 26.65 mm/min., which indicates the coincidence of the model properties with the corresponding properties of the simulated object.

The adequacy of individual submodels of the dependence of certain process parameters on various factors was also verified by comparing the calculated and experimental values. So, determining the height of the combustion zone using the appropriate submodel gives adequate characteristic dependencies, shown in Figure 2.

Thus, verification of the adequacy of the model showed the coincidence of the properties of the model and the corresponding properties of the simulated object.

6 Discussion

In order to discuss the simulation results, a study was made of factors affecting the agglomeration rate using the developed model. Using the created model, we studied the dependence of the vertical sintering speed on the solid fuel content at various heights of the sintered layer. The initial parameters of the charge: the basicity of the charge of 1.0; air suction rate 0.35 m/s. Adjustable parameters: solid fuel content in the charge 1-8 %; charge layer height 200-500 mm.

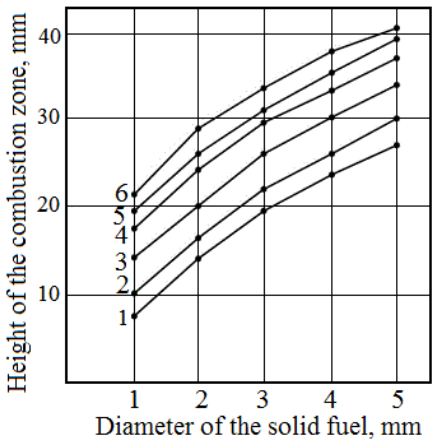

Fig. 2. The dependence the height of the combustion zone from the diameter of the solid fuel at different layer heights the height of the sintered layer, mm: 1 − 150, 2 − 200, 3 − 300, 4 − 400, 5 − 500, 6 – 600

The research results (Fig. 3) show an extreme dependence of the vertical sintering speed on the fuel content (the maximum is in the region of 3.5-3.7 % C), as well as an increase in the vertical sintering speed with a decrease in the layer height, which corresponds to the known laws of the theory of the sintering process.

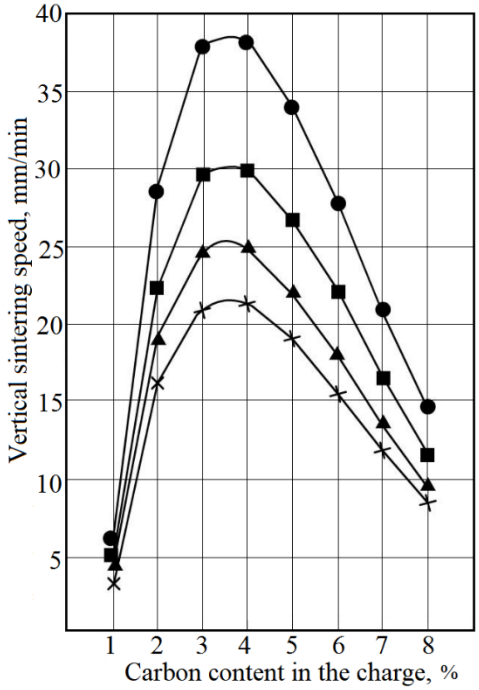

Fig. 3. The dependence of the vertical sintering speed on the fuel content in the charge at different layer heights, m: ● – 0,2; ■ – 0,3; ▲ – 0,4; × − 0,5.

A model study of the dependence of the vertical sintering rate on the flux content (a mixture of limestone and dolomitic limestone) at different heights of the sintering layer was carried out taking a constant solid fuel content of 4.0 %. Adjustable parameters: charge basicity 0-2.5; charge layer height 200-500 mm.

The research results (Fig. 4) show that limestone is an intensifier of the agglomeration process. With an increase in the basicity of the charge, the sintering rate increases by 12-14 % (a larger value corresponds to the lowest layer height).

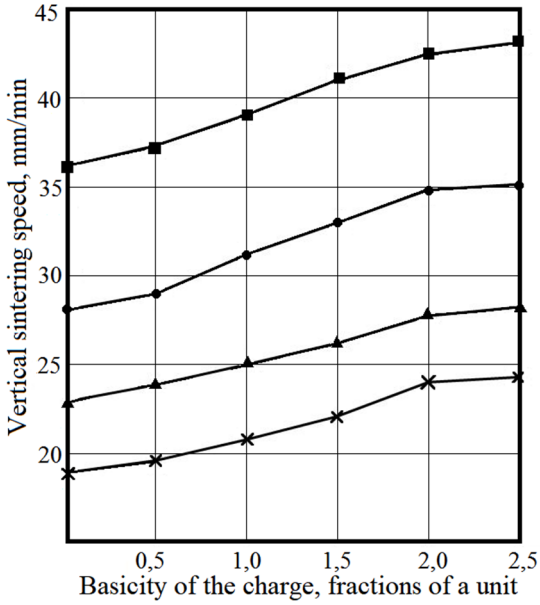

Fig. 4. The dependence of the vertical sintering speed on the basicity of the charge at different layer heights, m: ■ – 0,2; ● – 0,3; ▲ – 0,4; × – 0,5.

The negative effect of limestone supply is to reduce the porosity of the layer of pelletized charge due to an increase in the fraction of the fine fraction in it. The quantitative nature of this dependence is also presented in the corresponding submodel. With an increase in the limestone content in the charge to 25 %, the fraction of fines in the dry charge increases to 85 %. However, this improves the gas permeability of the charge directly during the sintering process. One of the reasons for this phenomenon is obviously a decrease in the content of relatively large granules (more than 10-12 mm) in the pelletized charge, which are prone to destruction in the drying and waterlogging zones during the sintering process.

A positive effect on the gas permeability of the sintered layer with increasing basicity also has a decrease in the optimal moisture content of the charge, since this increases the specific consumption of the heat carrier gas for moisture evaporation, which helps to preserve the strength of the granules.

Another explanation for the increase in the vertical sintering rate is possible, based on calculations of the apparent heat capacity of the charge at different limestone contents. Taking into account the heat that is released during the formation of calcium ferrites, an increase in the proportion of limestone in the charge reduces the maximum temperature in the solid fuel combustion zone, which is accompanied by an increase in gas filtration through the layer.

7 Conclusions

Thus, the performed studies show that the developed mathematical model of the process of moving the combustion zone of solid fuel in the sinter layer of the

sinter charge allows us to study the dependence of the vertical sintering speed on the parameters of the material composition and structural and gas-dynamic characteristics of the sinter charge layer. The obtained numerical description of the process is a local dynamic model, the adequacy of which is confirmed by the results of theoretical and experimental studies. Despite the local nature of the developed model, due to its versatility, it takes into account the main material and structural parameters of the sintering process, which affect the speed of movement of the solid fuel combustion zone, and as such can be considered as element of the universal software package of sintering process model [7].

The scientific novelty of the work consists in the development of a model that for the first time allows us to determine the speed of the agglomeration process without conducting experimental sintering, as well as to investigate the influence of the composition and structural characteristics of the charge on the sintering intensity.

The obtained results create prerequisites for choosing the sintering technology that provides the highest sintering speed and, consequently, the productivity of the sintering machine for specific sintering conditions. This fact is an important factor in ensuring the economic security of sintering production, a condition for its sustainable future.

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Researching of physicochemical and structural-phase transformations in carbothermal titanomagnetite concentrates reduction for sustainable development of raw materials base of metallurgical enterprises

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Abstract. This study displays results of carbothermal reduction researches of titanomagnetite concentrate obtained during complex apatite-titanomagnetite-ilmenite ore dressing. The mineral composition was analyzed and the structural and textural features of the titaniferous ore of Kropivensky deposit and the titanomagnetite concentrate obtained from it were revealed. The mechanism of solid-phase carbothermal the titanomagnetite concentrate reduction is investigated. Temperature-time parameters have been discovered to ensure the formation of both products with the maximum yields of iron and titania from metal and slag-phase during titanomagnetite concentrate reduction. One-stage resource-saving flow chart of titanomagnetite concentrate processing with mass fraction up to 25% TiO_2 is developed.. It allows to obtain two marketable products: granular cast iron (92-96.5% Fe, 3.4-3.7% C, 0.5% V) in 57% yield and titaniferous slag (50-55% TiO_2, up to 7.4% FeO) in 43% yield.

Introduction

Within the framework of the stable metallurgy development program, the team of the Ferrous metals metallurgy and foundry Department of Kryvyi Rih National University scientists deals with the following important tasks: improving the hot-rolled steel plate technology [1] and determining the optimal parameters for the electrical treatment of foundry steels during casting [2]. Another area of research is the development of recommendations for the complex titanium ores involvement in processing. [3]

The rapid development of the metallurgical complex has led to a reducing of quality iron ore reserves amount. In the near future, they will be replaced by complex ores that can meet the needs of ferrous and non-ferrous metallurgy companies. Ukraine has significant complex ore of apatite-titanomagnetite-ilmenite composition reserves. The technologies of their preparation for metallurgical conversion make it possible to obtain basic ilmenite and apatite commodity concentrates and, in addition, titanomagnetite, which can contain 46-52% of Fe and 20-25% of TiO_2.

Titanomagnetite concentrate is not currently processed by existing metallurgical enterprises in Ukraine, but it is a promising raw material for the sustainable development of cast iron, steel, titania (TiO_2) and metallic titanium. The development and implementation of processing technology for this concentrate will allow the storage of valuable mineral components in the waste heaps. Extant technologies include the use of two-stage processing, which consists of pre-reduction and ore-thermal electric melting, followed by separation into industrial products. These technologies are characterized by high energy consumption and environmental hazards. Therefore, research with the discovering and justification of technical and technological solutions for the processing of titanomagnetite concentrates with a high content of TiO_2goal is relevant and important for the sustained development of metallurgy.

In research works [4-7], a number of experiments were conducted on solid-phase reduction of titanomagnetite concentrates with mass fraction of Fe 56.5-64.5% and up to 16.7% TiO_2. It has been shown that slag with a wide range of chemical composition from 15.4 to 62.5% of TiO_2 were obtained after their reduction. This is an important basis for studying the iron-containing and titaniferous phases formation mechanism, as well as the allocation of Fe and Ti between them. The analysis of those studies` results does not allow us to completely determine the peculiarities of the structural-phase titanomagnetite transformations at different temperature-time parameters of the carbothermal reduction process. In addition, the titanomagnetite concentrates reduction process with a TiO_2 mass fraction of 20-25% has not been studied.

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For carbothermal reduction process, a titanomagnetite concentrate obtained after the apatite-titanomagnetite-ilmenite ore dressing of the Kropivensky deposit was used, having the following composition, mass fraction,%: 45.5 FeO; 23.0 Fe_2O_3; 22.03 TiO_2; 1.5 SiO_2; 1.2 Al_2O_3; 0.26 CaO; 3.4 MgO; 0.42 MnO; 0.516 V_2O_5; 0.04 Cr_2O_3 [8, 9].

Researched ore is low-concentrated, sometimes contain schlier with 1-2 m capacity of high-concentrated varieties. The total content of ore minerals does not exceed 10%. The ore has an apatite-titanomagnetite-ilmenite composition with variations in the ratio of titanomagnetite / ilmenite from 1/1 to 1/5. The amount of apatite is 1-3%. The ores of the deposit are characterized by a Fe/TiO_2 ratio from 1.5 to 4.0.

A defining characteristic of the magmatic process that has led to the titanium ores formation is the fact that minerals are being formed under conditions of constant change in the chemical composition of the residual melt and the individual components in it. In addition, differentiation (separation) of the melt and the arrival of new magma portions can occur. This creates even more complicated crystallization conditions, which are accompanied by the melting of previously formed minerals grains and even their complete melting and digestion. Lowering the temperature in the magmatic cell can lead to the separation of mineral phases already at the solid solution stage, such as ilmenite, as well as Mg – Al and Ti – spinels in magnetite. Sometimes magnetite in pyroxene and others. The peculiarity of all structures of the solid solution decomposition is a very small sized inclusions of one mineral in another (1-2 μm), which in the future, in the industrial ores processing leads to different technological difficulties.

Titanomagnetite is the predominant ore mineral in the ore deposit, in some samples its mass fraction can be up to 13.5% [10,11].

The following research methods were used: microscopy, spectral, structural-textural and X-ray fluorescence analysis.

For roasting and sintering concentrate by method ore coarsening charge, following materials were used: combined bentonite and FERROFORM polymer, flux additive CaF_2, and reductant graphite with minimal mineral content.

Results and discussions

In the study of polished sections under the microscope the titanomagnetite unusualness is noticeable, it is more similar to ilmenite in optical characteristics. If these minerals are separated, in the form of isolated grains, it is difficult to distinguish them. They are easier to distinguish in joint inclusions – by a noticeable reddish tint in the color of titanomagnetite (Fig. 1, a, b). In addition, ilmenite appears to be lighter, which is most likely due to the Fe_2O_3 impurity in its composition.

In some grains of titanomagnetite under the microscope, the lamellar ilmenite inclusions in the form of decomposition structures of a solid solution are easy to identify (Fig. 1, c, d). The partial oxidation and leaching of the magnetite component of titanomagnetite under the weathering bark on gabbro-peridotites impact seems to present a true picture of the titanomagnetite grains structure and composition. The study of such ore samples using a microscope made it possible to characterize the titanomagnetite under study, to understand its nature and to develop technologies for the mechanical ore dressing and the subsequent heat treatment of titanomagnetite concentrate.

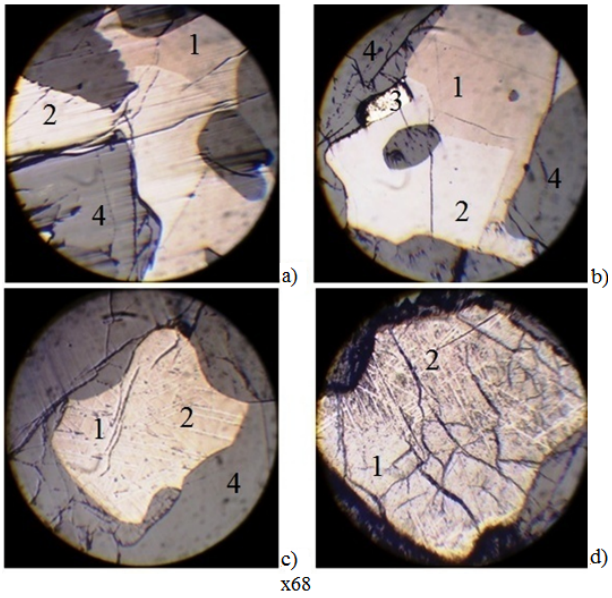


Fig. 1. Theilmenite and titanomagnetite ratio in joint inclusions: a) morphology of titanomagnetite and ilmenite grains; b) idiomorphism of ilmenite, apatite and sulfide compared to later titanomagnetite; c) lamellar inclusions of ilmenite in titanomagnetite; d) homogeneous titanomagnetite (lower part of the grain), which fades into decay structures with ilmenite plates (upper part of the grain). 1 – titanomagnetite (creamy with a reddish tint), 2 – ilmenite (white with a grayish tint), 3 – iron sulfides (white), 4 – apatite and silicates (different shades of gray).

Microscopy revealed that the grains of titanomagnetite, separated in space, have almost the same size (from 0.03 mm to 0.6 mm) as ilmenite, and are often with it in the fusion (Fig. 2, a, b, c) [12].

Single grains have a homogeneous (homogeneous) structure. Most often they are an aggregate of two or more mineral phases. They coalesce at a very thin submicron level, being elements of solid solution decomposition structures. Therefore, the term “titanomagnetite” is a fairly conditional term. Separate grains (and essentially aggregates of two or four mineral phases), whose chemical composition is determined by the FeO, TiO_2 and Fe_2O_3 content, are the titanomagnetits of this deposit. They have high magnetic characteristics. These grains are characterized by the different mineral phases’ presence: magnetite, ilmenite, and Al-Mg spinel in small quantities, which are formed after the collapse of the solid mortar. The ratio of these phases in titanomagnetite grains is different.

The magnetite forms the basis of the grain matrix into which the lamellar ilmenite or ulvospinel excretions are immersed and the micro-grain “relict-ilmenite”

(Fig. 2). The lamellar isolates of ulvospinel generally have a thickness of up to 2-3 microns. Single titanomagnetite grains have lamellar isolates of ilmenite or ulvospinel up to 8-10 microns in size. At the same time there are grains of titanomagnetite with different saturation structure and size of secretions (plates) of ilmenite or ulvospinel (Fig. 1, c, d and 2, a, b). The orientation of the plates according to the octahedral separation in magnetite is characteristic of titanomagnetite, often with the formation of lattice structures (Fig. 2, a).

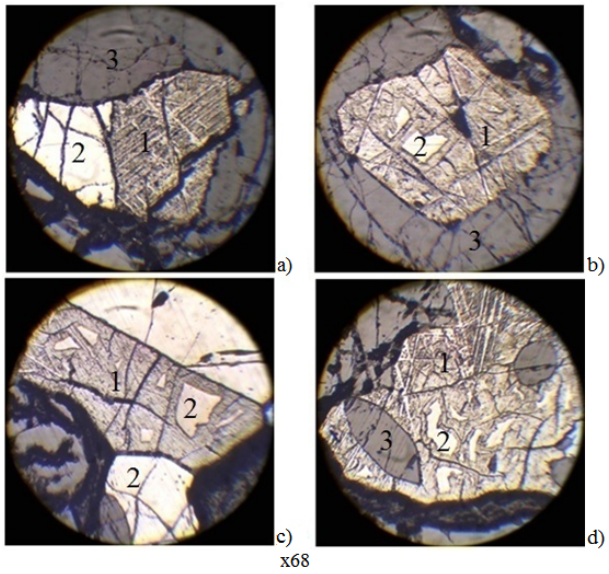


Fig. 2. Features of the titanomagnetite grains structure a) ore grain: left – ilmenite, right – lattice structure of titanomagnetite; b) octahedral titanomagnetite crystals with solid solution decomposition structure and relict inclusions of ilmenite; c) ilmenite in the form of free grains, relic inclusions and plates in the structure of the solid solution decomposition in the grain of titanomagnetite; d) lamellar ilmenite, semi-melted relict grains of ilmenite, incorporation of apatite crystals into titanomagnetite. 1 – lattice structure of titanomagnetite, 2 – ilmenite (light cream), 3 – apatite and silicates (different shades of gray).

The micrograin "relict – ilmenite" is often semi-alloyed, sometimes they are solitary, but more often concentrated in groups (Fig. 2, b, c, d). The size of micro-grains inclusions is 0.05 – 0.1 mm. These are micro inclusions its remains "Magnetite" magma beneficiateoned by titanium. The presence of "relict – ilmenite" micro grain causes a high (up to 25%) content of TiO_2titanomagnetite grains [13].

Titanomagnetite is also characterized by the presence of a higher concentration of V than in ilmenite. This is due to the fact that Fe has a close crystal-chemical bond with V, and since ilmenite has a smaller proportion of Fe, the concentration of V in it will be lower.

Based on the study of the morphological structures of apatite-titanomagnetite-ilmenite ore, the classification of titanomagnetite grains is made:
- grains with fine ilmenite in the magnetite matrix (Fe – 42.36 ± 2.18%, Ti – 14.47 ± 0.96%);
- grains having the structure of uniformly distributed lamellar secretions of ilmenite in the magnetite matrix (Fe – 34.25 ± 1.4%, Ti – 11.37 ± 0.37%);
- grains having the structure of equally distributed lamellar secretions of ilmenite and separate microgranules of "relict-ilmenite" in the magnetite matrix (Fe – 31.24 ± 1.73%, Ti – 18.65 ± 1.08%).

Analysis of these types of titanomagnetite concentrate grains confirmed their complex structure and showed that the reduction conditions of this concentrate will be significantly different from the reduction parameters of iron-containing magnetite concentrate.

The calculations show that the magnetite matrix of titanomagnetite grain contains up to 34.6% of Fe, and in the ilmenite particle – up to 15% of Fe. The different structure of the grains and their elemental composition make it necessary to determine the optimal temperature and time parameters for the reduction of the magnetite matrix and the release of ilmenite, which will achieve the maximum extraction of Fe and TiO_2 in the industrial products.

It is established that the obtained coils have satisfactory characteristics for their further reduction: porosity – 30-35%, compressive strength – 1.32 kg/pellet (for dry – 2.7 kg/pellet), reset strength – 4.2 times.

The process of carbothermalreduction of coils with a diameter of 10-14 mm was carried out in the temperature range of 800-1500 ºC.

Studies of the pellet's microstructure at different temperature-time parameters of the treatment process showed that the reduction of the titanomagnetite concentrate happened in two temperature-time periods, in which significant physicochemical and structural-phase transformations occur.

In the first period ("low-temperature zone", 800-1000 ºC) there is a physicochemical transformation of iron-containing silicates (olivine and pyroxene) with the formation of magnetite and its subsequent reduction to Fe^0. At 900 °C, solid-phase changes start in titanomagnetite grains. Around the grains appears a dark border of 10–15 microns thick, characterized by a higher titanium content (Fig. 3, a).

It happens as a result of the restoration of the magnetite matrix of the grain with the formation of Fe^0 in the form of droplets less than 0.1 μm and its diffusive removal beyond the grain boundary (Fig. 3, b).

At 1000 °C in volume of pellets solid-phase changes are accelerating. Up to 1 microns of Fe^0 appear. With increasing the holding time at this temperature up to 40 min, the intensity of both the reduction of the magnetite matrix in titanomagnetite grains up to 0.06 mm and the release of Fe^0 increases. There is an intense formation of a metal sponge (Fig. 3, c, d). In grains of more than 0.06 mm in size, the concentration of which is not more than 20% in the concentrate, solid-phase transformations with separation of Fe do not occur.

In the second thermo-time period ("high-temperature zone", 1000–1300 ºC), the accumulations of Fe^0 continue. Titanomagnetite grains complete the reduction of the magnetite grain matrix. At a temperature of 1200 ºC, "relic-ilmenite" and a grid of ilmenite remain in place of the titanomagnetite grains, which are inherited from the structures of decomposition of the solid mortar (Fig. 3, c).

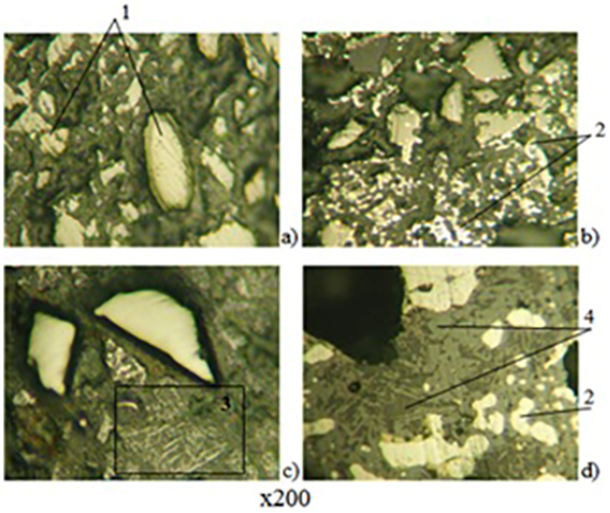


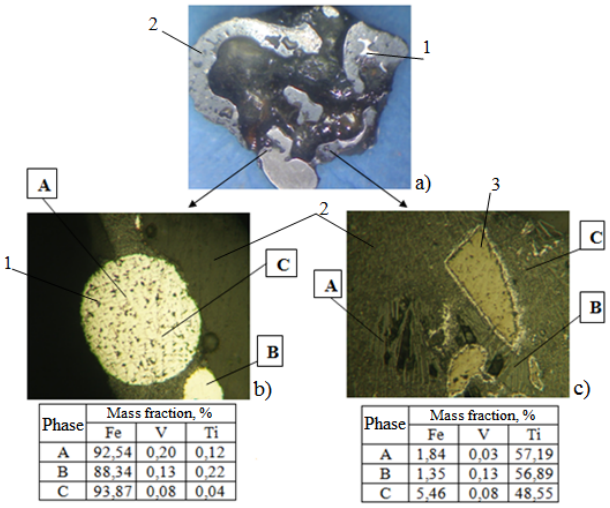
Fig. 3. Structural transformations in coils reduced at 900-1300 ºC: 1 – grains of titanomagnetite (cream color); 2 – allocation of metallic iron (white color); 3 – ilmenite mesh; 4 – slag phase (dark gray and gray).

Exposure for 5-40 min at 1300 ºC ensures the aggregation of Fe^0 clusters up to 0.1-0.2 mm, and shutter speed up to 50 min – the appearance of regions of Fe^0 spherical in diameter up to 2 mm. The slag titanium phase begins to form from the ilmenite mesh. At the endurance of 80 min, the enlargement of Fe^0 regions to 3.5 mm continues, the content of Ti decreases to 2%, but in them there are significant accumulations and separate inclusions of secretions with the content of Ti up to 31% (Fig. 3, d). The Fe content in the slag phase gradually decreases from 38% to 25%, and the Ti content increases from 23% to 39% (Fig. 3, d) [3].

For maximum extraction of Fe^0 and TiO_2 into the iron and titanium phase, a complete reduction of the magnetite particle in all grain types is observed, which is observed as a result of holding for 20 min at 1300 °C (Table 1), as well as further raising of the temperature to 1500 °C with holding 5 min. This ensures the reduction of FeO in the ilmenite particle of the grains. The total degree of metallization of the coils thus increases to 94%.

The reduced product (Fig. 4, a) is a shell-shaped porous formation of a slag phase with a wall thickness of 2-3 mm, and a separated iron phase in the form of spherical particles up to 30 mm (Fig. 4, b). The slag phase is mainly composed of thin-needle and thin-fiber aggregates of rutile and anatase with up to several micrometers thickness (Fig. 4, c).

Sometimes, in the slag phase, glass inclusions and single residual semi-melted titanomagnetite ore grains of 0.04 × 0.07 and 0.07 × 0.15 mm with a FeO border 1-3 μm thick are observed around them.



Phase	Mass fraction, %		
	Fe	V	Ti
A	92,54	0,20	0,12
B	88,34	0,13	0,22
C	93,87	0,08	0,04

Phase	Mass fraction, %		
	Fe	V	Ti
A	1,84	0,03	57,19
B	1,35	0,13	56,89
C	5,46	0,08	48,55

Fig. 4. Reduced product (a), the microstructure (b, c; x200) and the chemical composition (mass, %) Of the products of reduction: 1 – the separation of metallic iron (white color); 2 – slag titanium phase (different shades of gray); 3 – semi-melted grains of titanomagnetite (cream color).

Thus, the parameters of a two-step process for the reduction of titanomagnetite concentrate were determined, which ensure the formation of iron-containing and titaniferous products with maximum extraction of Fe^0 and TiO_2 in them. These parameters are: I degree – reduction of the magnetite particle with increasing temperature from 800° C to 1300 °C; II degree – restoration of ilmenite particle with increasing temperature from 1300 ºC to 1500 ºC.

It should be noted that the formation of metal granules from grains of titanomagnetite is a complex process that happens due to the diffusion of Fe^0 microparticles into the intergranular space with its subsequent enlargement due to autogenesis. The forces of adsorption attraction, which are caused by covalent, ionic, polarizing or intermolecular (dispersion) forces, have a significant effect. But several types of these forces are possible at the same time. As the temperature of the process increases, the formation of liquid metal clusters into a spherical shape continues due to coalescence (coagulation). In order to prevent impediments to the coagulation processes of the iron particles and the inhibition of the process of separation of the metallic and slag titaniferous phases, this phase must be converted to a visco-plastic state.

Table 1. Chemical composition of slag phase at the temperature reduction of during 800-1300 °C temperatures and holding time of 20 and minutes.

Holding time	Series of tests	Mass particles, %				
		Fe	Ti	V	Si	Mn
20 min	1	16.7	37.58	0.58	0.42	2.42
	2	14.4	32.97	0.17	0.85	0.47
Average		15.65±1.5	35.28±2.86	0.38±0.25	0.64±0.27	1.45±1.21
40 min	1	36.61	29.37	0.35	2.13	1.42
	2	42.13	30.68	0.22	1.42	1.81
Average		39.37±3.4	30.03±0.81	0.29±0.08	1.78±0.44	1.62±0.24

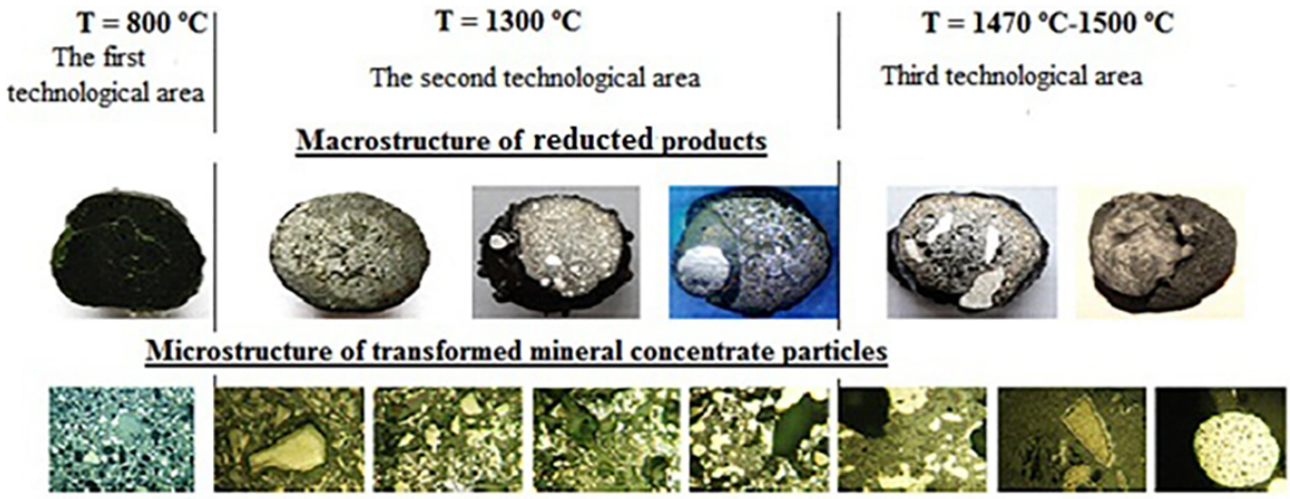


Fig. 5. Chart of structural-phase transformation in the carbothermal reduction of the pelletized titanomagnetite concentrate.

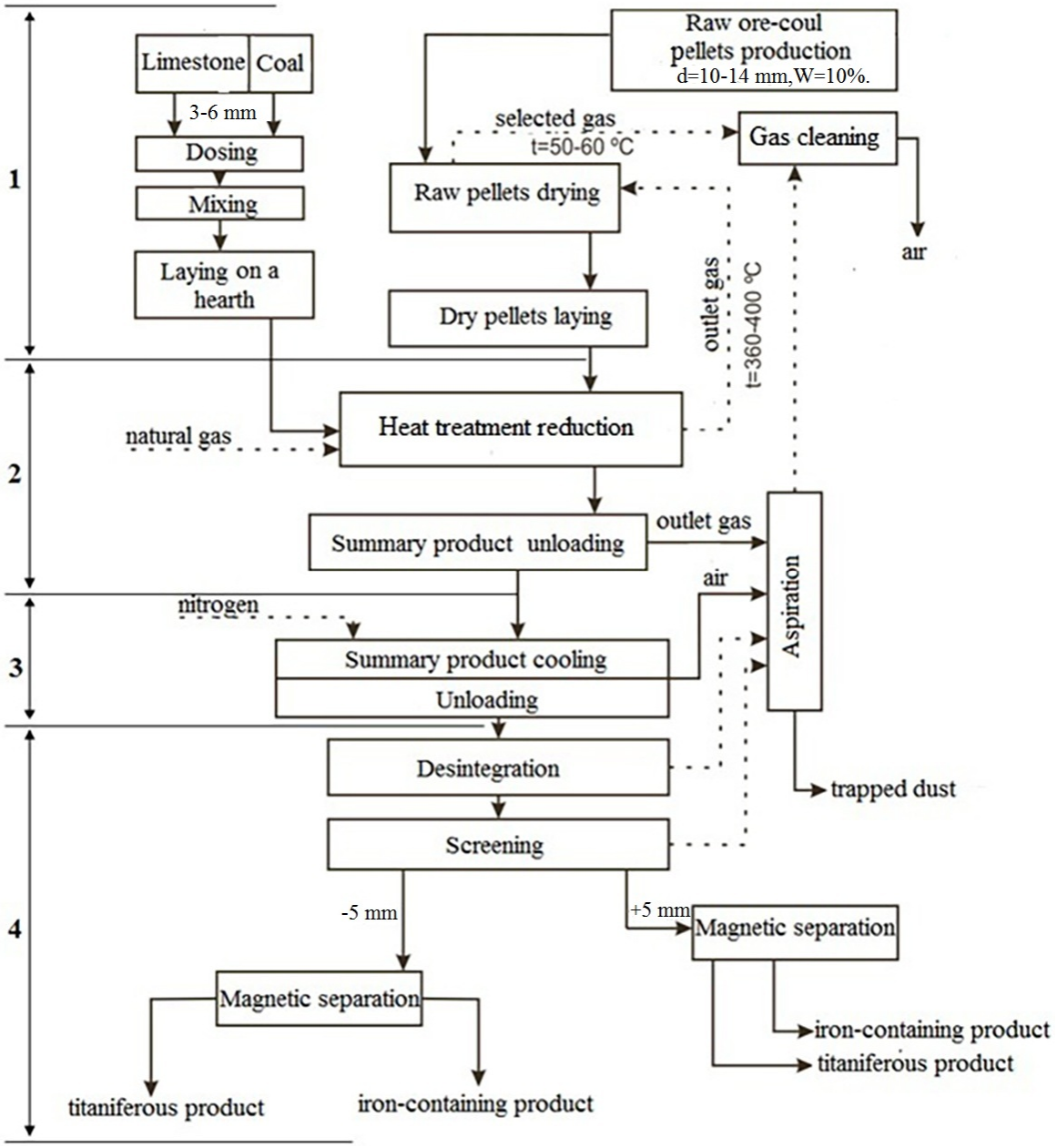


Fig. 6. Flow chart of titanomagnetite concentrate processing.

It is advisable to carry out the process of two-stage reduction with certain technological parameters in a direct reduction furnace with annular hearth, since the final product is not granulated iron, but granular cast iron. This oven has high operational reliability, economy and environment friendliness.

Chart of structural-phase transformation at certain parameters. The carbothermal reduction of the titanomagnetite concentrate in this furnace is shown in Fig. 5.

According to the results of the research, the working area of the furnace is divided into technological sections (Fig. 5):

section I – loading of the material and its heating from 600 °C to a temperature of 800 °C;

section II – heating from a temperature of 800 ºC to 1300 ºC with a speed of 20 ºC/min and holding for 15-20 min – indirect reduction of the magnetite part of the titanomagnetite grain;

section III – heating from a temperature of 1300 ºC to 1470-1500 ºC at a speed of 50 ºC/min and holding for 5 min – direct reduction of residual magnetite and FeO from ilmenite parts of titanomagnetite grains.

The flow chart of titanomagnetite concentrate processing for obtaining marketable products with maximum extraction of Fe^0 and TiO_2 in them was developed and tested (Fig. 6). This scheme includes the basic production operations: 1 – occlusion of charge materials and their drying, 2 – heating, reduction and melting of coils in a high-temperature unit, 3 – cooling the product; 4 – grinding and dividing of the obtained product into magnetic and non-magnetic fraction.

The yield of the iron-containing fraction was 57% in the form of cast iron granules (92-96.5% Fe; 3.4-3.7% C, 0.5% V), the yield of the slag fraction was 43% in the form of titaniferous slag with 50 -55% TiO_2 and up to 7.4% FeO.

Conclusions

As a result of the research, it was discovered that the structural-phase transformations during the carbothermal reduction of the pelletized titanomagnetite concentrate proceeds by the following scheme: physicochemical and structural transformations of the olivine and pyroxene minerals at 800 ºC; the beginning of the magnetite matrix reduction of grain with the iron diffusion into the intergranular space at 900 ºC; complete reduction of the magnetite component of grain with the ilmenite mesh and “relict-ilmenite” formation at 1200 °C; the emergence of the titaniferous phase as a result of the ilmenite grid reducing and the “relict-ilmenite” at 1300-1500 °C. The parameters of the two-step reduction process of titanomagnetite concentrate, which provide the formation of iron-containing and titaniferous products with maximum extraction of Fe^0 and TiO_2 in them, are experimentally discovered. I step – magnetite phase reduction with increasing temperature from 800 ºC to 1300 ºC and holding for 20 min at a final temperature (it provides complete reduction of the magnetite phase of grain). II step – reduction of ilmenite phase with increasing temperature from 1300 ºC to 1500 ºC with holding at a final temperature of 5 min. A one-stage resource-saving flow chart of titanomagnetite concentrate processing with a mass fraction up to 25% TiO_2 has been developed based on carbothermal reduction of pellets in an annular hearth furnace. It allows to obtain two marketable products: granular cast iron (92-96.5% Fe, 3.4-3.7% C, 0.5% V) in 57% yield and titaniferous slag (50-55% TiO_2, up to 7.4% FeO) in 43% yield.

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Recent studies on germanium-nanomaterials for LIBs anodes

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Abstract. The inherently law capacity of the classically used carbon-based anode is one of the major drawbacks hindering the wide application of lithium ion batteries (LIBs) in electric vehicles. Carbon replacement with materials possessing high theoretical capacity, such as germanium (Ge) represents one of the approaches used for ensuring wider LIBs' implementation. The main disadvantage of the Ge use is its huge volume change during the lithiation / delithiation, causing Ge-based electrodes pulverization, deterioration of the electrochemical properties and resulting in electrodes relatively short life. Usage of Ge based nanomaterials is regarded as powerful tool for overcoming the mentioned drawbacks. This paper reviews and discusses the very recent progress in the preparation and studying the Ge nanoparticles (NPs), Ge nanoalloys and Ge-based nanocomposites as attempts for preparation of advanced anodes for LIBs.

1 Introduction

The lithium-ion batteries are widely used and their application in portable electronics and electric vehicles or hybrid electric vehicles is expected to be increased. LIBs are rechargeable batteries possessing high energy density, low self-discharge and no memory effect. Every LIB (more correctly a battery pack) consists of gathered together electrically connected electrochemical cells and electronics for control and protection. The cell (that is the primary electrochemical unit) contains electrodes, separator, and electrolyte. In the most commercial cells the negative electrode (anode) is made of graphite.

The positive electrode is a lithium-based material. It can be a layered oxide (for example lithium cobalt oxide), a polyanion (like lithium iron phosphate), or a spinel (for instance lithium manganese oxide). The electrolyte usually represents a mixture of organic carbonates, typically ethylene carbonate (EC), diethyl carbonate (DEC), ethyl methyl carbonate (EMC), dimethyl carbonate (DMC), containing lithium complexes, such as lithium hexafluorophosphate ($LiPF_6$), lithium perchlorate ($LiClO_4$), lithium tetrafluoroborate ($LiBF_4$), lithium hexafluoroarsenate monohydrate ($LiAsF_6$), and lithium triflate ($LiCF_3SO_3$).

Anode and cathode allow lithium ions (Li^+) to move in and out of their framework, the Li^+ insertion process (lithiation) is called intercalation and the Li^+ extraction (delithiation) one – deintercalation. During the discharge an oxidation reaction proceeds at the anode and positively charged Li^+ and negatively charged electrons are formed. The Li^+ move through the electrolyte to the cathode where they are inserted in the cathode material (often forming a lithium compound) with the aid of electrons that are transported from anode through an external circuit to the cathode. When the cell is being charged, the reverse reaction occurs – the Li^+ and electrons move back into the negative electrode.

The capacity decrease in LIBs is most often due to the loss of lithium to the solid-electrolyte interphase (SEI) that forms at the negative electrode. Initially, during charging at temperature below 25 ºC metallic lithium is produced spontaneously on the electrode surface. Further the lithium reacts with electrolyte to form Li_2O, LiF, Li_2CO_3, and polyolefins. This is due to the fact that the electrolytes typically used in LIBs are not stable at the electrode operating potential during charging and they may decompose. At the beginning, SEI formation increases the electrode resistance to solvent decomposition but the increase in the SEI thickness with time leads to a gradual decrease of the LIB's capacity.

The commercial graphite exhibits a relatively low theoretical capacity of 372 mAh/g (electrode capacities are compared by using three measures: specific energy or gravimetric capacity (capacity per unit of mass), volumetric capacity (capacity per unit volume), and areal capacity (area-normalized specific capacity)). This fact leads to an intensive search for other materials. Materials forming alloys with Li, such as Si, Ge, Sn are actively researched as alternatives to carbon-based anodes for rechargeable LIBs due to their higher theoretical capacities in comparison to commercial graphite. For example, Ge possesses theoretical specific capacity of 1600 mAh/g (at 4.4 Li^+ per Ge atom), an electronic conductivity 10^4 times higher than silicon, and high Li^+ diffusivity (more than 400 times higher than that in silicon at room temperature) [1].

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The unsatisfying cycle life (due to the volume expansion / contraction during the lithiation / delithiation reaction, causing the formation of cracks, pulverization of the electrodes, destroying the conductive network of the electrode, thus deteriorating the storage capacity of lithium and worsening the cycle performance) appeared as one of the most challenging problems of the recently developed anode materials. Ge particles aggregation during the Li^+ insertion / extraction leads to an increase in the internal resistance and in Li^+ diffusion path resulting in inability of the internal Ge particles to participate in chemical reactions. The final result is capacity loss and more generally – poor electrochemical performance.

The investigations trying to solve the above-mentioned problems are going to the following directions: (a) alloying with the Li-active / inactive materials, (b) preparing nano-structured electrodes, and (c) surface modification by introducing conducting and / or nonconducting buffer components [2].

Application of nanostructured materials is considered a promising approach for bettering the electrochemical properties of electrodes. Nanostructured electrodes posses a very large specific surface area that can increase the contact area between the electrodes and the electrolyte. This big contact area is able to accelerate the exchange of ions and electrons at the electrode / electrolyte interface. Furthermore, owing to their very short internal diffusion paths, the nanoscale materials possess much higher ionic or electronic conductivities compared to their bulk counterparts. In addition, they can also resist to bigger mechanical deformation during charge / discharge cycling. Since Ge possesses high theoretical capacity, good electrical conductivity and fast Li^+ diffusivity, Ge-based nanomaterials have recently attracted considerable attention as LIB electrode materials.

Recently, different nanoscale Ge-based anodes with a variety of morphologies have been developed to raise the electrochemical performances of these anodes and the results are presented in the worldwide literature.

The most comprehensive overview of anodes for LIBs is provided by Hu and co-authors [3]. The paper covers studies carried out till the first quarter of 2016. The paper has extensively reviewed the preparation and the entire characterization of nanoparticles (NPs), nanowires (NWs), and nanotubes (NTs) made of single Ge, Ge alloys with metals (such as Cu, Sn), with semiconductors (such Si, Se), and germanium chalcogens alloys such as GeS.

Preparation of electrodes based on Ge/carbon nanotubes (CNTs), Ge/graphene, Ge-reduced graphene oxide-CNTs (Ge-RGO-CNTs), Ge-reduced graphene oxide nanofibres (Ge@RGO NFs) aimed at achieving a longer cycling life of the LIBs and their characterization is also presented by the same paper.

A special attention is paid to the preparation and characterization of core-shell structural electrodes because of their high conductivity, excellent stability and the ability to prevent the significant volume changes in the Ge electrode during the charge/discharge process. LIB anodes based on Ge@C core-shell; Ge@Cu core-shell; Ge@C/graphene, Ge@C/RGO, Cu@Ge core-shell NW; and 3D TiO_2@Ge core-shell nanorod arrays on carbon textiles are briefly discussed.

Attention is drawn also to LIB anodes made of Ge based nanomaterials (NWs, NPs, and nanorods) that are ternary alloys and their composites (such as Cu_3Ge/Ge NWs, Cu_3Ge/Ge@graphene aerogel), as well as double oxides and their composites (such as $CuGeO_3$, $Cu_3Ge/GeO_x/CuGeO_3$ NWs, $CuGeO_3$ NWs / graphene composites, $CuGeO_3$@RGO composites, $Ca_2Ge_7O_{16}$ NWs on carbon textiles, $Ca_2Ge_7O_{16}$ NW/ graphene sheet nanocomposite, Zn_2GeO_4 NWs and nanorors, Zn_2GeO_4-GO nanocomposite, Cd_2GeO_4 NWs, Cd_2GeO_4 NW / CNT and the Cd_2GeO_4 NW/GO/CNT nanocomposite films, $PbGeO_3$ NWs, $SrGe_4O_9$ and $BaGe_4O_9$ NWs).

The results from testing the all above-mentioned materials as anodes in cells for LIBs are also presented.

Additionally, a brief discussion is given on the performance of LIBs electrodes made of germanium oxide (GeO_2) NPs, GeO_2 NPs/RGO composite, and GeO_2-C fibre composite.

Influence of the LIB's electrolyte type, the discharge current density, the working temperature, the cycling rate[1], the shape and morphology of the Ge-based materials has been presented when it was discussed in the original papers.

For all presented electrodes data are provided on the specific capacity (mAh/g) – initial and after cycling, current density (mA/g) and the number of charge-discharge cycles. However, for comparative purposes, the data presented have to be used cautiously, going to the original papers to check the exact cycling rate and the number of cycles related to the reported specific capacities and current densities.

An other review paper is devoted to the advances in studies on the synthesis, optical properties and applications of germanium nanocrystals, including their use as anodes for LIBs [4]. The paper covers studies carried out in the period 2010-2015 and only two of the papers reviewed in [3] are referred to also in [4]. The author pays special attention to the Ge nanocrystals (NCs) use in anodes for LIBs. The Ge NCs/RGO composite and a composite of Ge NCs encapsulated within carbon nanofibers ((Ge)0D@(CNF)1D) are presented, including means for those composites preparation, their characterization and results from their testing as anodes for LIBs (specific capacity (mAh/g) – initial and after cycling at different rate, and the number of charge-discharge cycles).

Figure 1 presents schematically the major Ge-based nanomaterials studied until 2016 as potential anode (active) materials for LIBs.

Having in mind the importance of developing high-performance LIBs and the exponentially growing studies in the area, we consider that it would be useful for the

[1] A C-rate is a standard unit of the rate at which a battery is discharged with respect to its maximum capacity. A 1C rate denotes that the discharge current will discharge the whole battery in 1 hour. As an example, for a battery with a capacity of 100 Ah, 1C is equal to a discharge current of 100 A, a 5C rate for this battery would be 500 A. (http://web.mit.edu/evt/summary_battery_specifications.pdf)

reader to be supplied with up-to-dated information on the subject.

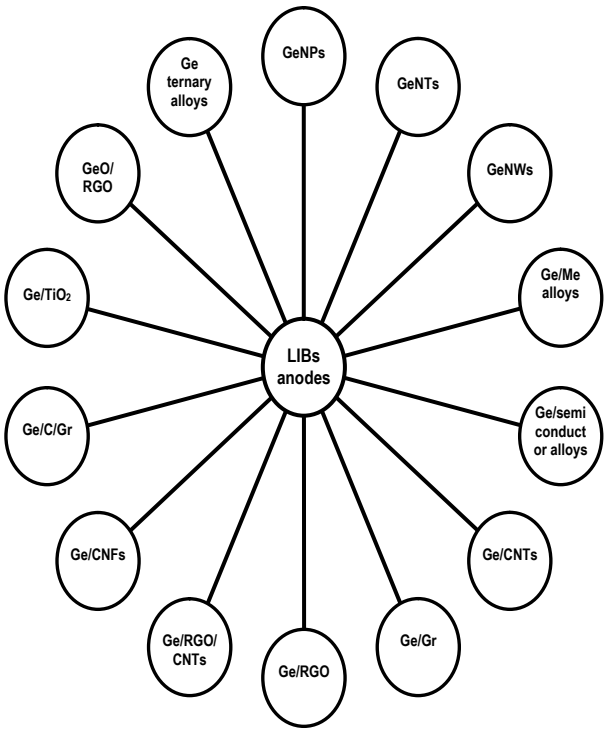

Fig. 1. Schematic representation of the major Ge-based nanomaterials studied until 2016 as potential anode (active) materials for LIBs

In this mini-review article, we overview the further development in the use of Ge-based nanomaterials and nanocomposites for LIBs' anodes by covering the studies in the recent three years.

2 Recent approaches for preparing germanium based nanomaterials for high-performance anodes for LIBs

The studies aimed at improving the performance of Ge containing LIBs anodes in the recent 3-4 years have continued in the following directions: nano-structured germanium, germanium oxide based materials, germanium alloys based nanomaterials and preparation of electrodes based on Ge and carbon (or its derivatives).

2.1 Nano-structured germanium

A new direction in the synthesis Ge-based nanomaterials for LIBs is proposed that relays on pulsed laser-assisted electrodeposition from ionic liquid at room temperature [5]. The utilized ionic liquid was 1-ethyl-3-methyl-imidazolium bis (trifluoromethylsulfonyl) imide ([EMIm]Tf2N) that did not require supporting electrolytes as is the case with organic solvents. The laser irradiation allowed for controlling the size, shape, and distribution of nanoparticles since it ensured clustering and vertical growth of Ga nanospheres and further development of Ge nanowires (non-branched and branched). The pulsed laser irradiation facilitated the direct electrodeposition of Ge nanowires on a copper (Cu) foil.

The characteristics of the produced material were studied utilizing home-made cells. The Ge NW electrode was used to prepare coin-type half cells (2025R size) by applying Li metal as the counter electrode. The separator was a microporous polyethylene (PE) and the electrolyte was 1 mol/L $LiPF_6$ in EC-DEC mixture. The prepared Ge nanowire anode exhibited an initial discharge capacity of 1646 mAh/g and initial charge capacity of 1278 mAh/g. The large initial discharge capacity and irreversible capacity loss measured were assigned to the irreversible formation of SEI. However, the capacity reversibility was much better in the next cycles and the capacity of 884 mAh/g was retained after 50 cycles at 0.2C, while the coulombic efficiency (CE) was higher than 96%. The capacity decay was less pronounced compared to that observed for Ge nanoparticle film prepared by non laser-assisted electrodeposition.

The studied Ge nanowire electrode showed reversible capacities of 1230, 1160, 1070, 960, and 730 mAh/g at 0.1C, 0.2C, 0.5C, 1C, and 2C, correspondingly. In addition, the capacity returned to 1100 mAh/g when the rate was decreased to 0.1C. These findings show that the properties of pure Ge anodes can be improved by pulsed laser assisted ionic liquid electrodeposition. The improved properties of thus prepared electrode were assigned to the laser-assisted transformation of the amorphous Ge deposits from films in the absence of laser irradiation to polycrystalline structures (nanowires and branched nanowires) under laser irradiation. This structure supplies channels facilitating the transport of Li^+. The result is higher diffusion rate of Li^+. The polycrystallinity of the nanostructures also averts pulverization of the electrode materials during LIBs' cycling by facilitating volumetric expansion throughout the entire nanostructure.

Preparation of porous structures is considered an efficient way for mitigating the negative effect of the LIBs' volume expansion and contraction during lithiation and delithiation. In this line, a 3D ordered macroporous (3DOM) nickel (Ni) framework (Ge/3DOM-Ni) was prepared by using drop-coating technique to attach Ge nanoparticles to the Ni framework [6]. Germanium nanoparticles were produced by reduction of germanate ions with $NaBH_4$, the former were prepared through reaction of GeO_2 with NaOH. Thus prepared Ge nanoparticles were dispersed in ethanol by ultrasonication. The obtained suspension was drop-coated onto the heated 3DOM-Ni framework. The self-supporting porous Ge/3DOM-Ni electrodes were produced by annealing the 3DOM-Ni framework, bearing the Ge nanoparticles, at 500 °C for 2 h in Ar atmosphere.

To study the properties of thus prepared anodes a coin-type half cells (2025R size) were assembled. Microporous PE was used as the separator, Li metal as counter and reference electrode, and 1M $LiPF_6$ in EC – DEC (1:1 vol.%) as the electrolyte. The discharge–charge study was carried out at a current density of 0.2C (1C is approximately 1600 mA/g) within the potential range of 0.01–2 V (vs. Li^+/Li). Initially a low CE of

53.3% was recorded, corresponding to the initial discharge and charge capacities of approximately 1869 and 996 mAh/g. This effect is assigned to the SEI layer formation. The discharge and charge capacities for the second cycle were 1053 and 1052 mAh/g, correspondingly, ensuring the CE of approximately 100%. No definite variation was observed in the specific charge capacities of the Ge/3DOM-Ni electrodes in the initial 10 cycles, pointing at good structural stability. After 100 cycles a specific charge capacity of 610 mAh/g was observed while the CE remained c.a. 100%.

The rate performance of the Ge/3DOM-Ni electrode was studied at rates of 0.1C, 0.2C, 0.5C, 1C, 2C, 5C, and 10C. The obtained respective reversible capacities of the Ge/3DOM-Ni electrodes were approximately 1337, 1042.5, 930, 817.5, 685, 460, and 270 mAh/g. The good performance of the Ge/3DOM-Ni electrode is mainly attributed to the 3DOM-Ni framework, since the easily accessible macroporous channels ensure efficient transport pathways for electrolyte and Li^+ and highly conductive framework for electron transport. The high porosity of the prepared electrode (confirmed by SEM observations) helped to avoid the negative effect of the volume enlargement of the Ge nanoparticles at cycling. The work showed that porous Ni frameworks are good supports and current collectors for Ge-based LIBs anodes. The use of polymer binders and conductive substances is avoided, thus the specific capacity is increased.

Recently a study is reported on the effect of mass loading on the areal capacity, capacity retention, and rate performance in high-capacity Ge electrodes for LIBs [7]. The results are of interest, since the application of electrodes with an areal capacity over 3 mAh/cm^2 meets different obstacles, such as electrode delamination from the current collector, increased resistance – electronic and ionic, substandard electrolyte penetration, and underutilization of the electrode at high current densities. To overcome the problems, a porous Ge was prepared by reducing GeO_2 under hydrogen atmosphere at 450 °C. Further a the slurry was prepared by mixing 70 wt.% of the produced active material with the binder (20 wt.% poly (acylic) acid) and the conductive agent (10 wt.% acetylene black). The electrodes were elaborated by tape casting of the produced slurry.

To study the electrochemical behaviour of the prepared electrodes CR2016 coins cells were fabricated. Metal Li was used as the counter electrode for the half cells and commercial $LiCoO_2$ electrodes were applied in studies on the full cell cyclic performance. The electrolyte applied consisted of 1M $LiPF_6$ in mixture of ED, DEC and DMC (1:1:1 by volume).

The electrochemical behaviour of the Ge electrode was studied using galvanostatic charge/discharge process in the range of 0.02 and 1.2 V vs Li/Li^+. At a current density of 1000 mA/g, 340 stable cycles were achieved and the final specific capacity was approximately 1300 mAh/g for the mass loading of c.a. 1 mg/cm^2. The slight capacity drop in the initial cycles was assigned to the formation of SEI, as well as to some loss of electrical contact due to the rearrangement of active materials. The increase in the specific capacity at further cycling is assigned to the electrode activation by the deeper lithiation into the active materials. The first cycle CE was 60%, it increased to 92% for the 2nd cycle, and reached approximately 99% for the 10th cycle.

The electrode cyclic performance was studied (up to 1800 cycles) at the high current density of 5C (i.e. 8 A/g, since 1C = 1600 mA/g) and at the low loading of 0.56 mg/cm^2. A CE over 99% was achieved starting from the 3rd cycle. This long term cycleability at the high rate was explained by the porous morphology of the Ge electrode that was able to sustain the lithiation induced stress without undergoing pulverization. In addition, the electrode with such morphology provided better electrolyte accessibility and simultaneously ensured shorter Li^+ diffusion lengths.

To evaluate the practical behaviour of the electrode, the electrochemical characteristics of a full cell consisting of Ge anode and lithium cobalt oxide cathode was studied. At a current density of 1 mA/cm^2 the areal capacity at the end of 180 cycles was 0.68 mAh/cm^2 at CE of 99.6%.

Transmission electron microscopy (TEM) and selected area electron diffraction were used to study the electrode morphology before and after cycling and the phase transformation. The results indicated that the electrode stability resulted from the ability of the individual grains to keep the electrical contacts between them, even at big changes in the volume due to the lithiation.

Macroporous (MP) Ge@TiO_2 composite, consisting of nanoscale Ge network skeleton wrapped with TiO_2 particles was prepared by dealloying of $Ge_{4.5}Ti_{0.5}Al_{95}$ alloy via its immersion in 0.01 mol/L NaOH solutions at 25 °C for 4 h [8]. During the selective dissolution of Al, Ge atoms were brought together and formed three dimensional (3D) network nanostructure with high porosity. Meanwhile Ti atoms were oxidized and further (by a spontaneous aggregation) formed TiO_2 particles layer that covered the porous Ge surface.

In order to study the lithium storage performances of the prepared Ge@TiO_2 material, CR2032 coin-type cells were fabricated where Ge@TiO_2-based material served as the anode active substance. Anodes with pure Ge as active material were also prepared for comparison. The other materials included in the slurry used to prepare anodes, besides the active materials, were Super P, and sodium alginate. Cu foil was used as current collector. The counter electrode was a lithium foil, and the separator – a microporous membrane. The electrolyte was 1 mol/L $LiPF_6$ dissolved in the mixture of EMC, DMC and EC (1:1:1 – a volume ratio) with an addition of 3 v.% vinylene carbonate (VC) that acts as film forming additive.

Studies on the cycling performances and CEs of Ge@TiO_2 anode and pure Ge anode were carried out at current density of 400 mA/g. The Ge@TiO_2 electrode provided a reversible capacity of 963 mAh/g after 100 cycles while the capacity of pure Ge was 418 mAh/g, thus suggesting the more stable lithium storage performances of the Ge@TiO_2 material.

The cycling performances of MP Ge@TiO_2 and pure Ge anodes at current density of 3200 mA/g were also studied. Ge@TiO_2 maintained reversible capacity of

716.7 mAh/g after 300 cycles, while the capacity of pure Ge electrode at the 300th cycle was 126.4 mAh/g. TEM images showed that the structure of pure Ge underwent serious fracture and collapse after cycling while the Ge/TiO_2 material preserved its original porous network architecture.

The rate performances of MP Ge@TiO_2 and pure Ge electrodes were studied, as well. The Ge@TiO_2 electrode exhibited specific discharge capacities of 1182.2, 1040.4, 955.3, 820.0, and 774.8 mAh/g at the current densities of 160, 400, 800, 1600 and 3200 mA/g, correspondingly. The pure Ge showed lower capacity at all current densities and a discharge capacity of only 134.6 mAh/g at 3200 mA/g. When the current density was back to 160 mA/g (after it was 3200 mA/g) the specific capacity for Ge@TiO_2 returned to 1036.5 mAh/g indicating very good rate performance.

The excellent characteristics of the prepared material were explained by its structure. The 3D macroporous network with its channels accelerates the movement of electrons and ions during lithiation/delithiation process. The robust TiO_2 layer ensures mechanical strength and prevents the direct contact between Ge and electrolytes, thus hindering the continuous increase of SEI which causes the capacity decrease.

2.2 Germanium oxide based nanomaterials

Due to its high theoretical capacity of 2152 mAh/g, in the case that it reversibly stores 8.4 Li^+, GeO_2 is considered as an encouraging anode material for LIBs [9]. In addition, GeO_2 is cheaper than pure Ge. However, its fast implementation in LIBs is hindered by the GeO_2 poor electrical conductivity and the very big volume changes during the charge/discharge process, resulting in the degradation (pulverization) of the electrode material, unstable SEI and as a result poor performance. In an attempt to obtain novel GeO_2-based anode materials with enhanced performance, preparation of porous GeO_2 nanoparticles through thermal decomposition of $(Hbipy)_2[Ge(C_2O_4)_3]\cdot 2H_2O$ in air atmosphere has been proposed [9]. The idea was to use the ability of porous structures to relax the mechanical strain resulting from the volume expansion during cyclic process, as well as their large surface area facilitating electrode-electrolyte interface, and thin walls ensuring fast diffusion of Li^+.

The prepared porous GeO_2 nanoparticles possessed an average size of 200 nm, pores of 4 nm, BET surface area of 74.0 m^2/g and total pore volume of 0.208 cm^3/g.

When used as LIB's anode the materials exhibited a discharge capacity of 2578.8 mAh/g at current density of 100 mA/g. Even at current density of 2 A/g, the reversible specific capacity was 184.2 mAh/g. After the high-rate measurements, the specific reversible capacity was 727 mAh/g when the current density was set back to 100 mA/g. This finding points at good electrochemical reversibility and structure stability.

A comparison of commercial GeO_2 and the synthesized porous GeO_2 nanoparticles pointed at the superiority of the latter. After 100 cycles at 100 mA/g, the porous GeO_2 possessed a reversible capacity of 581.9 mAh/g for Li^+ storage, while that of the commercial GeO_2 was 256.5 mAh/g. The good performance of the prepared material is assigned to the synergism of nanoscale, porous structure and low crystalline structures formed during the synthesis.

One-pot environmentally friendly synthesis of amorphous Ge oxide-carbon (GeO_x-C) hollow composite has been proposed by using citric acid (CA) as reductant of the germanium ions obtained by dissolving GeO_2 in NH_4OH [10]. The amount of the added reductant influenced the thickness of the resulting hollow structure, but the hollows' size of the GeO_x materials was not changed. Under the optimum ratio of CA to GeO_2 13-16 nm shells were formed and this material showed the best electrochemical performance.

The LiB anode prepared using this material exhibited a capacity of 930 mAh/g after 100 cycles at rate of 0.3C, while the CE was 99.9%.

The cycling stability of the GeO_x-C hollow composite was studied by gradually applying C-rate from 0.1C to 10C. At that, the specific capacity of the sample slowly decreased from 956 to 612 mAh/g. Nevertheless, when 0.5 C was applied after 10C, the reversible capacity come back to 935 mAh/g showing a very good performance. The repetitive fast cycles charge/discharge' carried out at rate of 2C showed that after 400 cycles the reversible capacity was 757 mAh/g, (approximately 90% retention compared to the second cycle) pointing at good cycling stability.

It has been found that during the lithiation/ delithiation process the thickness of the GeO_x-C hollow composite electrode changed by approximately 12%, while the thickness of an electrode prepared from commercial GeO_2 changed by up to 150%. The HRTEM analysis of the GeO_x-C hollow composite showed well preserved hollow structure and uniform distribution of Ge and O atoms even after 400 cycles.

The enhanced electrochemical performance of the GeO_x–C hollow composite was assigned to the synergistic effect of the hollow structure with optimized thickness of the shells, amorphous nature, and the presence of conductive carbon. The composite shell layers supplied a surface for formation of stable SEI layer by avoiding the direct contact between the electrolyte and the anode. Availability of an internal void space ensured free expansion of the anode material without increasing the volume of the entire electrode. All these features allowed for an effective accommodation of volume change and facilitated transport of electrons during charge/discharge process.

2.3 Germanium alloys-based nanomaterials

Germanium alloying represents one of the ways for mitigating/avoiding the structural pulverization and loss of electrical conduction paths between the active materials and current collector in LIBs' anodes. In line with these efforts free standing non-carbon electrodes were prepared by mixing Ge and Cu nanowires [11]. The electrodes were tested as anodes for LIBs. Half-cells (of CR2032 type) were prepared using as working electrode

the produced free standing NW fabric, Li metal foil was the counter electrode. The electrolyte was 1 M $LiPF_6$ in 3:7 (v/v) fluoroethylene carbonate/dimethyl carbonate (FEC/DMC) and it was loaded on a microporous PE separator. The material prepared under optimum conditions exhibited initial charge and discharge capacities of 1348 mAh/g and 1107 mAh/g corresponding to the CE of 82.1%. Its capacity retention was 80.3% after 50 cycles.

High-resolution SEM and TEM images of the electrodes before and after 100 cycles showed that before cycling Ge nanowires waved with each other into the fabric structure. The X-ray spectroscopy (EDS) of the contact point revealed that the atomic ratio of Cu to Ge was 3:2, which proved the formation of copper germanide. After cycling, the nanowire composites were coated by a uniform SEI layer.

The free standing NW fabric electrodes possess the following advantages for application in LIBs: (i) The elaborated electrode structure needs neither a metal foil current collector nor polymer binders in the production process. As a result, the whole electrode is considerably lighter than conventional electrodes made by slurry coating on metal foils; (ii) The existence of the raw material in the form of wires supplies many intersections between NWs (like 3D interconnectivity) leading to an accelerated electron transport; (iii) The space between the NWs can alleviate the volume changes during alloying and dealloying process and improve the electrolyte penetration leading to easier Li^+ diffusion in the electrode.

The Cu content and the annealing temperature were found as the two main factors determining the electrochemical performance of the free standing NW anode electrodes.

Use of core-shell array nanostructures as LIBs' anodes is able to significantly improve the electrochemical performance, especially the high-rate capability. Cobalt-germanium core-shell nanowire array anode (Co-Ge CNA) was synthesized by template-free approach applying direct deposition of a Ge layer on the surface of the preliminary synthesized Co NW arrays [12]. RF-sputtering method was used.

To study the performance of the produced material as anode for LIBs, 2025 coin-type half cells were assembled with a metallic lithium foil as the counter electrode, 1M solution of $LiPF_6$ in EC / DMC (1:1 by volume) as electrolyte and polypropylene micro-porous film as a separator.

At a current density of 320 mA/g the initial discharge and charge capacities of Co-Ge CNA were 1994.8 and 1441.4 mAh/g correspondingly, resulting in an initial Coulombic efficiency (ICE) of 72.3%. The irreversible capacity loss in the first cycle is assigned to the SEI formation. In the further cycles the Co-Ge CNA anode exhibited practically constant capacity and it was 1535 mAh/g after 100 cycles.

The rate performance of Co-Ge CNA electrodes was studied under different current rates in the range of 0.2C – 5C. The discharge capacities of 1493, 1482, 1467, 1357 and 1239 mAh/g were recorded at 0.2, 0.5, 1, 2 and 5C (= 8000 mA/g), correspondingly. However, when again a current of 0.2C was applied, the Co-Ge CNA electrodes showed a capacity of ~1446 mAh/g and a stable cycling performance. The good rate performance is assigned to the core-shell array nanostructures that are able to provide vigorous mechanical support, fast electron transport, and improved contact to the current collector.

2.4 Nanocomposites of germanium and carbon-based materials

Composites consisting of Ge NPs and carbon-based materials continue to be considered among the most promising materials for preparation of LIBs' anodes, since carbon coating on Ge particles acts as a buffer layer effectively limiting volume expansion and aggregation of Ge NPs. In comparison with amorphous carbon coating, the ordered mesoporous carbon (OMC) in addition to providing large surface area, uniform pore size and good conductivity, can be used as a matrix that contains electroactive material, exercising a confining effect and maintaining the integral structure. Combining Ge nanoparticles with the advantages of ordered mesoporous structure is considered as a plausible strategy for the synthesis of high-capacity, long-cycle life electrode materials.

A composite consisting of Ge NPs embedded in spherical ordered mesoporous carbon (S-OMC/Ge) was prepared by impregnating the ammonium salt of Ge in the pores of OMC, followed by high temperature pyrolysis and H_2 reduction [13].

The electrochemical performance of the synthesized composite as an active anode material was tested by preparing CR 2032 coin cells. The anode contained the active material, acetylene black, and binder polyvinylidene fluoride (PVDF) at a mass ratio of 75:15:10, the current collector was Cu foil. A lithium plate was the counter electrode, and the electrolyte was 1.0M $LiPF_6$ in EC – DEC at ratio 1:1 vol.%.

The cycling behaviour of S-OMC/Ge based electrodes as well as of electrodes based on pure spherical OMC (S-OMC) and pure Ge materials were studied in 160 cycles at the current density of 100 mA/g. The capacity of S-OMC sample was 643 mAh/g after 160 cycles. The capacity of Ge electrode was 173 mAh/g after 3 cycles, showing a rather poor cycling performance. The composite S-OMC/Ge sample exhibited a stable circulation in the 160 cycles, with capacity of 996 mAh/g.

The rate performance of the S-OMC/Ge electrode was evaluated by applying different current densities. The measured reversible discharge capacities were 1025, 934, 807 and 681 mAh/g at applied current densities of 100, 200, 500 and 1000 mA/g, correspondingly. When the applied current density was returned to 100 mA/g, the reversible capacity was stabilized at 890 mAh/g after 60 cycles. The reversible capacities measured under the same conditions for S-OMC and pure Ge samples were much worse. The cycle stability of S-OMC/Ge electrode was studied also at high current density of 1 A/g. The

electrode maintained a reversible capacity of 530 mAh /g after 200 cycles and the CE was stable, at 99.2%.

The proposed explanation of the high capacity of S-OMC/Ge composite was by the complete structure formed by Ge particles (that possess a high theoretical capacity) even distribution in the mesoporous carbon.

It was found that the content of Ge had an effect on the performance of S-OMC/Ge composites. The low Ge content was not enough to ensure the impact of the Ge high theoretical capacity, while use excessive Ge lead to Ge agglomeration and blocking of the mesoporous carbon pores, which affected the overall performance of S-OMC/Ge composite.

The good performance of the prepared composite is assigned to the synergistic effect between the support of spherical OMC and the high capacity provided by dispersed Ge particles. The spherical ordered mesoporous carbon supplies channels able to alleviate the volume changes during the lithiation / delithiation cycling and ensures high electrical conductivity.

Decreasing the aggregation of Ge NPs occurring during electrodes' cycling represents another direction for improving the properties of Ge NPs based anodes for LIBs. NPs' anchoring on conductive substrates, such as graphene (Gr), CNTs, and RGO or NPs encapsulation in hollow carbon active material is accepted as the problem's solution. These carbon materials prevent large volumetric expansion thus ensuring long-term stability and high electrical conductivity resulting in high power of the batteries.

The reactive sites of nitrogen doped single walled carbon nanohorns (N-SWCNHs) were utilized by favourably growing of germanium nanocrystals (Ge NCs) onto their conical tips by applying oleylamine as a reducing agent [14]. The prepared Ge@N-SWCNHs composite was studied as an active anode material for LIBs. For this purpose CR2032 coin cells were elaborated with Li chips as reference and counter electrode, the separator was dried glass fibers membrane and the working electrode was Ge@N-SWCNHs composite, casted on a copper foil. The slurry casted on the foil consisted of 70 wt.% Ge@N-SWCNHs composite (containing 70 wt.% Ge), 20% Super-P carbon and 10% PVDF in N-methyl-2-pyrrolidone (NMP). The electrolyte was 1 M $LiPF_6$ dissolved in 1:1 mixture of EC and DMC with 5 v.% of VC as an additive.

The capacity of Ge@N-SWCNHs composite based electrode after 5 cycles stabilized at 1435 mAh/g while for an electrode based on Ge NCs as an active material the capacity was 1046 mAh/g. The higher capacities obtained for Ge@N-SWCNHs composites were assigned to the lower activation energies permitting entire utilization of active material. The capacity retention of electrodes based on Ge NCs and Ge@NSWCNHs composites was tested for over 100 cycles. Pristine Ge NCs and Ge@N-SWCNHs composites showed stable discharge capacities of 811 and 1285 mAh/g after 100 cycles, correspondingly. The main part of the delithiation capacity in Ge@N-SWCNHs composite was lost during the initial 10 cycles (6%) while the loss was 2.5% for the remaining 90 cycles. The CE of Ge@N-SWCNHs composite after 20th cycle was higher than 95%, and for the 80th cycle it was practically 100%.

The rate behaviour of Ge@SWCNHs composite was studied at various charge / discharge rates and compared with the behaviour of Ge NCs and of pristine NSWCNHs under the same conditions. At rates of 0.1C, 0.4C, 0.8C, 1C, 2C and 5C the capacity of Ge@N-SWCNHs composite based electrodes was 1420, 1193, 935, 866, 611, 366 mAh/g, correspondingly. The capacity of Ge NCs based electrodes was 908, 762, 599, 462, and 271 mAh/g at 0.1C, 0.4C, 1C, 2C and 5C correspondingly, while the capacity of pristine NSWCNHs was 48, 36, 26, 15 and 9 mAh/g at 0.2C, 0.4C, 0.6C, 0.8C and 1C respectively. When after applying the highest discharge rate, it was returned to 0.1C, the capacity of Ge NCs based electrode was 850 mAh/g, while the Ge@SWCNHs based electrode recovered its original capacity of 1413 mAh/g.

The high storage capacities and the excellent rate behaviour of Ge@N-SWCNHs were assigned to the very good contact between Ge NCs and N-SWCNHs leading to high utilization of the active material. The preferential growth of Ge NCs on the tips of N-SWCNHs averts the NCs aggregation after many charge/discharge cycles.

Production of N-SWCNHs is relatively cheap and scalable and this makes the synthesized composite a promising candidate for LIBs anodes.

A layered germanium phosphide (GeP_3) – carbon black nanocomposite was prepared by high-power ball-milling technique [15]. The nanocomposite was tested as active material for LIBs anode. A button-type electrochemical half cell was assembled where Li metal was applied a as the counter and reference electrodes, the separator was Celgard 2400 membrane, and electrolyte was 1 M $LiPF_6$ dissolved in EC – DEC (1:1 by volume), containing 5% fluorethylene. The electrode exhibited a capacity of 1450 mAh/g after 30 cycles at rate of 100 mA/g. At high current (1900 mA/g) the capacity was 860 mAh/g. The CE was in the range 87 – 93% after 100 cycles. The observed good electrochemical and cycling performances were assigned to the presence of very small GeP_3 nanocrystallites (3–5 nm) in the amorphous C matrix and to the created short Li^+ ion diffusion paths.

Recently Ge coating for a 3D porous carbon on the surface of Ni foam has been prepared by ionic liquid electrodeposition followed by annealing [16]. Thus a 3DVoid/Ge@C composite has been produced. The material has been tested as a LIB anode. At current densities of 0.1, 0.2, 0.5, 1, and 2 A/g, the electrode has shown a reversible specific capacity of 1592.9, 1054.9, 921.3, 771.4, and 471.2 mAh/g, correspondingly. The good performance of the prepared material has been ascribed to (a) the elasticity of the carbon sheet that facilitates the contact with Ge nanoparticles and protects pathways for the Li-ions transport and (b) the created 3D micro-nano void structure that decreases the damage from large volume changes during the intercalation and deintercalation process of Li^+ ions.

Three-dimensional nitrogen-doped graphene foam (NGF) has been prepared that contained interconnected pores and encapsulated Ge quantum dots. The obtained material was covered with polydimethylsiloxane to

produce yolk-shell nanoarchitecture [17]. The material performance was tested by preparing two-electrode CR2025-type coin cells. The separator was porous polypropylene film, lithium foil was used as the counter electrode and 1M solution of $LiPF_6$ in the mixture EC – DMC – DEC (at volumetric ratio of 1:1:1) was used as an electrolyte. Thus prepared nanocomposite (Ge-QD@ NG/NGF /PDMS) showed a reversible capacity of 1220 mAh/g at current of 1600 mA/g, preserved for 1000 cycles. The material exhibited high rate capability of more than 800 mAh/g at current of 64 A/g and 200 cycles. The averaged coulombic efficiency was 99.7% for the studied 1000 cycles. The excellent behavior of the prepared nanocomposite is assigned to the creation of internal void space that ensured better relieving the volume expansion during lithiation. In addition, the N-doped graphene outer shell decreased significantly the exfoliation, pulverisation and aggregation of Ge. The elaborated material is suitable for preparing flexible electrodes.

In an attempt to overcome the negative effect of volume changes during the charging/discharging and the aggregation of Ge particles, a core-shell structured germanium@carbon (Ge@C) NPs were homogeneously anchored on the RGO nanosheets to obtain Ge@C/RGO hybrid [18]. Initially Ge NPs were prepared by a mechanochemical reaction between GeO_2 and Mg powders. Further, Ge NPs were coated with polydopamine films, thus core-shell structured germanium@polydopamine (Ge@PDA) composite was prepared. The next step was the Ge@PDA anchoring on the graphite oxide (GO) making use of the dopamine strong adhesion, followed by calcination to form the Ge@C/RGO hybrids.

The electrochemical behavior of the prepared composite was studied using CR2025 coin-type cells in which working electrode consisted of active material (namely Ge@C/RGO, as well as Ge@C – for comparison), Super P, and lithium polyacrylate at weight ratio of 8:1:1, mixed with deionized water to form homogeneous slurry. Further, Cu foil, serving as a current collector, was coated with the slurry, cast in disks and dried. Li metal was used for counter and reference electrodes, and glass fiber for separator. The electrolyte was 1 M $LiPF_6$ dissolved in EC – DMC (1:1 by volume) with and addition of 5 wt.% fluoride ethylene carbonate (FEC).

Initially charge and discharge specific capacities were 1692.3 and 1258.5 mAh/g at C/10 (the current density of 1C rate was 1600 mA/g), corresponding to an ICE of 74.4%. This low ICE was assigned to decomposition of electrolyte and SEI formation. The initial discharge and charge capacity of the Ge@C, under the same conditions, were 1495.3 and 1252.1 mAh/g, correspondingly. The higher ICE of the Ge@C compared to the Ge@C/RGO was explained by the higher specific surface area of the latter leading to more surface side reactions and thicker SEI layers. After the second cycle, the CE of Ge@C/RGO electrode reached over 98% and kept at that value for up to 600 cycles.

The reversible capacity of Ge@C/RGO electrode after 600 cycles at discharge rate of 2C was 1074.4 mAh/g, which is 96.5% of the capacity at the 2nd cycle at 2C. For comparison, the reversible capacity of the Ge@C electrode after 600 cycles at 2C was 362.6 mAh/g indicating that only amorphous carbon layers cannot ensure stable long-term cycling performance.

Results from SEM and TEM analyses showed that after 600 discharging / charging cycles the Ge@C electrode suffers from significant pulverization and most of the active materials have lost contact with the current collector. Under the same conditions the Ge@C/RGO based electrode kept its surface morphology and structural stability. This is assigned to the high elasticity of RGO which was able to buffer the stress generated during the lithiation / delithiation of Ge.

The rate capability of Ge@C/RGO and Ge@C electrodes was studied at different current densities. At the rates of 5C, 10C, 15C, and 20C the Ge@C/RGO electrode exhibited reversible capacities of 1319.0, 1104.1, 879.4, and 711.6 mAh/g respectively. Under the same current densities, the Ge@C electrode reversible capacities were 988.9, 511.0, 293.1 and 204.3 mAh/g, respectively. When the rate was decreased to 0.2C the both electrodes recovered high capacity. After 200 cycles of lithiation/delithiation, no significant drop of capacity was observed at rates from 1C to 10C. The specific capacity of Ge@C/RGO electrode after 200 cycles decreased to 436 mAh/g at rate of 20C. However, this is still higher than the theoretical capacity of graphite anode (372 mAh/g).

The excellent rate performance of the Ge@C/RGO electrode is assigned to the double carbon matrix composed of amorphous carbon and RGO nanosheets. The carbon layers ensure conductive pathways for diffusion of electrons and Li^+. The homogeneous and continuous carbon layers in the core-shell structured Ge@C composite alleviate the large volume changes of Ge during lithiation / delithiation and improve the conductivity of Ge electrode. The uniform anchoring of the core-shell structured Ge@C particles onto the surface of RGO decreases the agglomeration of Ge@C composites and betters the active materials' utilization. The highly flexible RGO nanosheets decrease the stress resulting from the multiple volume changes and enhance the structural stability of electrode during cycling. In addition, Gr nanosheets and carbon shells create a hybrid conductive matrix, which improves the electronic conductivity and minimizes the volume change of Ge.

Similarly, a double-layered protective structure was synthesized in which the hollow cubic Ge@C hybrids were evenly dispersed on RGO sheets, thus forming Ge@C-RGO composite [19]. To prepare the composite Ge-bearing precursor ($NH_4H_3Ge_2O_6$) was dopamine-coated and further subjected to carbothermal reduction processes to obtain a Ge@C composite where the carbon is N-doped. Further, the cubic Ge@C was dispersed on the RGO. The RGO along with the carbon layer formed a double carbon layer structure protecting Ge particles.

The electrochemical properties of the as-prepared material were studied using CR2032 coin-type cells. The Ge@C-RGO composite was applied as an active material. It was mixed with conductive carbon black and the binder (PVDF) at a mass ratio of 80:10:10, and

dissolved in NMP to prepare a suspension, cast on a Cu foil (current collector). Thus prepared system was used as an anode, Li metal was the counter electrode and the electrolyte was 1.0M LiPF6 in EC – DEC (1:1 by volume) and 5 wt.% FEC. For comparative purposes, cells using Ge@C or Ge as active anode material were also prepared and studied.

It was found that the discharge capacities of Ge@C-RGO, Ge@C and Ge electrodes at 100 mA/g for 200 cycles were 1183, 567 and 202 mAh/g, correspondingly. The reversible capacity of Ge@C-RGO based electrode at current of 1 A/g for 200 cycles was 710 mAh/g, and the CE reached 99.30%.

The rate capability was studied at specific currents of 100, 200, 500 and 1000 mA/g. The capacities delivered by Ge@C-RGO were 999, 796, 718, and 664 mAh/g correspondingly, while the Ge@C electrode exhibited capacities of 589, 540, 461 and 418 mAh/g under the same conditions. When the specific current returned back to 100 mA/g, the capacities were 991 and 576 mAh/g for Ge@C-RGO and Ge@C respectively, indicating good reversibility of the both electrodes. At the same time, the pure Ge electrode showed a continuous decline in capacity at each current rate, indicating its poor electrochemical stability.

The outstanding electrochemical performance of the Ge@C-RGO based electrode is assigned to the formation of a double-carbon layer protective structure in which the hollow cubic Ge@C hybrids are evenly dispersed on the graphene sheets. The connected carbon shells, as a support structure, keep the shape of the material, alleviating the changes during the cycling, and the Ge@C core-shell structure ensures space for the volume expansion of Ge particles. RGO as a supporting substrate ensures good dispersion and fixation of Ge@C hybrids and with its large-area and high-flexibility buffers the stress caused by volume changes during charging / discharging. The N-doped carbon shell and the graphene network speed-up the transport of Li^+. The dispersed small Ge nanoparticles shorten the Li^+ transport path. The both effects contribute to the improved overall conductivity of Ge@C-RGO electrode.

Chen and coauthors reported in situ synthesis of Ge/RGO composites using GeO_2, as Ge source and $NaBH_4$ as reductant. The process was assisted by a cationic polymer – poly(diallyldimethylammonium chloride [20]. In this synthesis GeO_3^{2-} anions were adsorbed on cationic polymer-modified graphene oxide sheets by means of an electrostatic interaction. Further, in-situ reduction was carried out leading to the formation of ultrafine Ge nanoparticles (ca. 5 nm) on RGO sheets thus creating uniform sandwich-like structure.

The prepared composite was studied as an active material for LIB, using two-electrode CR2032-type coin cells. Besides the prepared composite, the working electrodes contained conductive agent (acetylene black) and binder carboxymethyl cellulose sodium at weight ratio of 8:1:1. The mixture was dispersed in deionized water and thus formed homogeneous slurry was uniformly coated onto pure Cu foil (serving as current collector), dried and cut into disks used as the working electrodes. Lithium foil was applied as both reference and counter electrodes. The electrolyte was 1.0M $LiPF_6$ dissolved in EC – DMC (1:1 by volume) containing 5 wt. % FEC. A full Li-ion cell was also prepared with a cathode, based on commercial $LiFePO_4$. The $LiFePO_4$ electrode was made by mixing 80 wt % of $LiFePO_4$, 10 wt% of acetylene black and 10 wt % of PVDF in NMP. Further, the slurry was spread on an Al foil and dried. Before fabricating the full cell, the Ge/RGO anode was pre-lithiated by placing it in direct contact with a lithium foil in the presence of the cell electrolyte.

It was found that the amount of used RGO influences the electrochemical behavior of the Ge/RGO composite. For the composite with the optimal RGO content the initial charge and discharge specific capacities were 2100 and 1184 mAh/g respectively, resulting in an ICE of 56.4%. The relatively low ICE was assigned to the formation of SEI films. The CE increased to ca. 95.0% at the 3rd cycle, and after 5th cycle became above 99.0% and remained at that value after the 100 cycles at current density of 0.2 A/g.

After 100 cycles the Ge/RGO-based electrode exhibited discharge capacity of approximately 960 mAh/g at 0.2 A/g, while the specific capacity of the prepared for comparative purposes pristine Ge-based electrode was 503 mAh/g after 100 cycles. The improved specific capacity of Ge/RGO-based electrode was explained with the high electrical conductivity and large specific surface area of the RGO matrix.

The rate performance was studied at different current densities. The specific capacities of Ge/RGO based electrode at 0.1, 0.2, 0.4, 0.8, 1, 2 and 5 A/g were 1290, 1194, 1112, 1036, 985, 877 and 631 mAh/g, correspondingly, while (for comparison) the specific capacity of pure Ge was 141 mAh/g at 5 A/g. When the current density of Ge/RGO based electrode was returned back to 0.2 A/g, the reversible capacity recovered to 1177 mAh/g.

The long-term cycling behavior of the Ge/RGO based electrode with the optimal RGO content was assessed at a current density of 1 A/g. The initial discharge capacity was 940 mAh/g, and it was 705 mAh/g after 350 cycles. Even at a high discharge rate of 5 A/g the reversible capacity of the Ge/RGO based electrode was 480 mAh/g after 250 cycles.

Furthermore, the coin-type full cell with the Ge/RGO composite as anode and commercial $LiFePO_4$ as cathode (at 85 mA/g) delivered an initial charge capacity of 149 mAh/g and discharge capacity of 131 mAh/g, which corresponds to the ICE of 87.9%.

The full cell still possessed a good cycling stability with a specific capacity of 120 mAh/g after 100 cycles at 0.5C. The Ge/RGO//$LiFePO_4$ full cell showed reversible capacities of 156, 152, 134, 115, 95, 62, 41 and 16 mAh/g at 0.1C, 0.2C, 0.5C, 1C, 2C, 5C, 10C and 15C, correspondingly. When, after the high current discharge, the rate was returned back to 0.2C, the capacity measured was 151 mAh/g. These findings point at the applicability of the Ge/RGO composite as anode in commercial LIBs.

The outstanding electrochemical performance of Ge/RGO composite is assigned to the elaborated nanostructure and to the resulting synergistic effect

between Ge NPs and RGO sheets. The two-dimensional structure and large surface area of the RGO facilitates the uniform dispersion of Ge NPs in RGO matrix, prevents their agglomeration and ensures more active sites for lithium storage. The Ge/RGO composite supplies enough void space to buffer the volume change of Ge and maintain high structural stability during cycling. RGO (when in optimal concentrations) with its high electrical conductivity promotes the electron transport. Its large area ensures better contact with the electrolyte and shortens the transport distance of Li^+ ions thus contributing to the superior rate capability.

Very recently germanene-reduced graphene oxide $GeCH_3$/RGO nanocomposites have been synthesized and studies as anode materials for LIBs by using home-made 2032 cells [21]. The counter electrode was lithium metal, the separator – Celgard 3500 membrane and the electrolyte – 1 M $LiPF_6$ dissolved in an EC – DEC – DMC mixture (at 1: 1: 1 in volume) with 2% FEC. The results revealed that the reversible capacity of the material prepared with 30 wt% RGO content (the optimum composition) used as anode was 1195 mAh/g after 5 cycles, and even after 100 cycles it was 1058 mAh/g showing a stable work. The CE was 98%. Even after 500 cycles, the capacities of the material with optimal composition were 439 and 288 mAh/g at current densities of 0.5 A/g and 1 A/g correspondingly, and the respective CE were 98.58% and 99.31%.

Only several months ago a material based on mixed Ge oxide and RGO has been presented [22]. The $CuGeO_3$/RGO nanocomposite makes use of high capacity possessed by $CuGeO_3$ and stable framework created by the RGO. Thus prepared composite was tested as anode active material for LIBs electrodes. The electrode was made of 80 wt% $CuGeO_3$/RGO, 10 wt% conductive acetylene black and 10 wt% binder (PVDF). CR2032-type coin half cells were prepared. The counter electrode was metallic Li and the electrolyte consisted of $LiPF_6$ dissolved in EC – DEC (at ratio 1:1) with addition of 5 vol% of FEC. It has been found that composite $CuGeO_3$/RGO containing 30 wt% GO exhibits very good electrochemical performance. It possessed a reversible capacity of 909 mAh/g and high CE of 91.49% at the current density of 100 mA/g after 200 cycles. The specific capacities of the prepared composite were 709.4 mAh/g, 609.7 mAh/g and 523.4 mAh/g when it was cycled successively at 200 mA/g, 500 mA/g and 1000 mA/g. At restoration of the current density to 100 mA/g, the capacity recovered to 747.6 mAh/g. The good electrochemical characteristics of the $CuGeO_3$/RGO composite were assigned to the combined effect of the crystalline $CuGeO_3$ nanorods and RGO sheets framework. The $CuGeO_3$ nanorods ensure direct transport tunnels for lithium ions, while the RGO sheets supply a stable conductive network having large specific surface area for even dispersion of the $CuGeO_3$. In addition, the RGO skeleton restricts the excess volume expansion of $CuGeO_3$, thus preventing the pulverization of the electrode during the lithiation/delithiation process.

A brief summary of the studies carried out in the recent 3–4 years on Ge-based nanomaterials preparation and testing as anode materials for LIBs is presented in Table 1.

Table 1. Brief summary of the recent 3-4 years studies on Ge-based nanomaterials for LIBs anodes.

Material	Capacity, mAh/g	Current density, mA/g	Charge-discharge cycles demonstrated	Ref.
Ge NWs	884	320	50	5
Ge/3DOM-Ni	610	320	100	6
Porous Ge	649 (1300)	8000 (1000)	1800 (340)	7
Ge@TiO_2 composite	963 (717)	400 (3200)	100 (300)	8
GeO_2 NPs	582	100	100	9
GeO_x-C composite	930 (757)	630 (4200)	100 (400)	10
Ge NW/ Cu NW composite	889	1300	50	11
Co-Ge core-shell NW array	1535 (1239)	320 (8000)	100 (45)	12
S-OMC/ Ge	996 (530)	100 (1000)	160 (200)	13
Ge@N-SWCNHscomposite	1285 (866)	160 (1600)	100	14
GeP_3-C black composite	860 (1450)	1900 (100)	100 (30)	15
3DVoid/Ge@C	990 (1300)	100 (100)	100 (10)	16
Ge-QD@ NG/NGF/PDMS	1220 (800)	1600 (64000)	1000 (200)	17
Ge@C/ RGO hybrid	1074.4	3200	600	18
Ge@C-RGO hybrid	1183 (710)	100 (1000)	200 (200)	19
Ge/RGO composite	960 (705 and 631)	200 (1000 and 5000)	100 (350)	20
$GeCH_3$/ RGO composite	1058 (439)	200 (500)	100 (500)	21
$CuGeO_3$/RGO composite	909 (523)	100 (1000)	200 (40)	22

3 Conclusions and outlook

As a conclusion it can be said that Ge NPs, Ge nanoalloys and Ge-based nanocomposites have been and are being widely studied for their ability to serve as advanced anodes in LIBs. These materials allow overcoming the problems related to volume expansion / contraction during the lithiation / delithiation reaction, while ensuring high reversible capacity and high rate under the applied test conditions.

However, studies on the cycling performance of the electrodes, based on the developed materials, seldom reach the cycles of the commercially used batteries. Further investigations in this direction are needed, with higher number of charge / discharge cycles.

Most of the cells assembled with the developed anodes resemble primary cells, the studies using as counter-electrode materials applied in real LIBs are very scarce. Studies of whole cells where the developed

materials are working with cathodes based on commercially used materials are highly needed.

Efforts must be continued to find the conditions for convenient production of large quantities of nanomaterials for the preparation and testing of larger batteries, rather than individual electrochemical cells.

Finally, we can say that Ga-based nanomaterials are promising active matter for advanced anodes for LIBs but still much work is required for their implementation in the commercial batteries.

In addition, since the sodium ions cannot intercalate into graphite in a reversible manner, the Ge-based nanomaterials deserve more attention as eventual anodes for sodium-ion battery.

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Dynamic load modelling for tank containers with the frame of circle pipes and structurally improved fittings

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Abstract. Higher efficiency of bulked cargo transportation along international transport corridors can be achieved with a resource-saving tank container described in the study. A characteristic feature of a tank container is the use of circle pipes as the carrying elements of the frame. In order to decrease impact loads between fittings of the tank container and fitting stops of the flat wagon at shunting impacts, the authors suggest filling fittings with viscous or viscoelastic materials of dumping or anticorrosive properties. The study also deals with modelling dynamic loading for the suggested tank container. The accelerations obtained were considered in strength calculations for a tank container as components of the dynamic loading. It was determined that the maximum equivalent loads did not exceed the admissible loads. The research will promote designing new-generation tank containers of improved technical, economical and ecological properties, and improve the working efficiency of combined transportation.

1 Introduction

Higher efficiency of bulked cargo transportation along international transport corridors has necessitated introduction of specialized transport means.

At present oil products are transported by tank wagons and tank containers. And it should be mentioned that recent years have witnessed a clear tendency to transfer part of bulked cargo transported from tank wagons to tank containers due to the mobility of the latter. And in recent years transportation of bulked cargo by tank containers is already estimated at the level of 18% annually out of the total bulked cargo turnover and this rate is going to increase.

Therefore, on-time delivery of oil products needs new-generation tank containers. Some characteristic operational features should be taken into account as early as at the designing stage, particularly the structural loading for different means of transport.

One of the most difficult transportation in terms of power load on the carrying structure is transportation of tank containers by rail flat cars. It is taken that at shunting impacts of flat cars loaded with tank containers the rear stop of an automatic coupling is under a force of 3.5 MN [1-3]. It is considered that the tank container sustains an acceleration of 4.0 g. However, with displacements between fitting stops and fittings the acceleration value can considerably increase. It can harm tank containers in operation and require an unscheduled repair. Therefore, while designing tank containers, it is of primary importance to guarantee their constructional adaption to certain operational conditions and compliance with the strength and durability requirements

2 Analysis of recent researches

At present, problems of improved carrying structures of vehicles have been considered by many engineers and designers in Ukraine and other countries. However, a further development of technical, economical and operational characteristics of rail transport means requires an extensive search for new engineering solutions [4-7].

Thus, study [8] deals with transfer of a heat flow through the carrying structure of a container. It describes simulation of a heat flow through the multilayer plastic support.

The results of optimization of the carrying structure of a tank container are given in [9]. The study confirms the need to design and implement tank containers as transport means. An improved tank container for transporting light oils was designed.

Tests on metal and composite containers under low temperatures are described in [10]. The study identifies some types of containers advisable for transporting certain types of cargo with consideration of low ambient temperatures.

It should be mentioned that the studies under examination do not consider problems of designing resource-saving tank containers.

The results of the research into the stressed state of an ISO tank container by the finite element method with

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ABAQUS software suite are given in [11]. The calculation was made under the static loading according to ISO 1496-3. The objective of the calculation was to define deflections of the frame angles and vertical deflections of the reservoir.

An improved structure of the support platform on the tank wagon for fluid cargo is presented in [12]. The strength calculation was made by the finite element method in Lira software.

However, the studies examined do not pose the problem of optimization of the carrying structures of tank containers to minimize the material capacity.

Considering the analysis of literature resources, we can conclude that, by far, the problems of designing resource-saving tank containers are not sufficiently highlighted.

The purpose of the article. The purpose of the article is to highlight characteristics of modelling dynamic loads on tank containers with frame of circular pipes and structurally improved fittings.

3 Results and discussion

In order to decrease the material capacity of a tank container the authors suggest optimization with the minimal material capacity criterion. A TK25 tank container manufactured by VAT Zarechinskiy Plant of Chemical Machine Building (ISO: 1CC) was taken as a basic structure (Fig. 1).

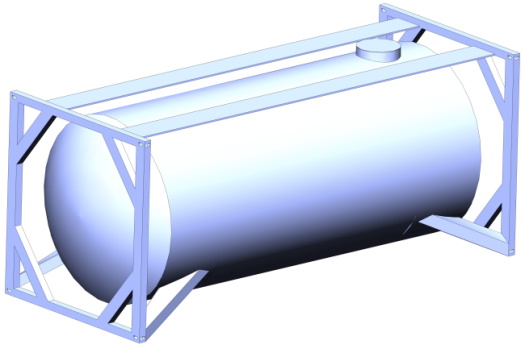


Fig. 1. A 1CC tank container

The tank container consisted of a frame (of rectangular cross-section pipes) and a tank; it was fixed on the flat wagon with corner fittings.

A prospective approach in achieving the objective is implementation of profiles, as the carrying elements of the frame, which provide lower metal structural capacity and meet the strength requirements. An analysis of prospective profiles for car building industry, and the experience gained by other machine building industries confirmed the importance of applying circular section pipes as the carrying frame elements [13].

The authors suggest replacing rectangular pipes for circular pipes as the elements of the carrying structure of a tank container.

The vertical pipe diameter was chosen on the basis of geometrical features of the fitting (D = 152 mm). The variation was made by changing the width of the wall S of the pipe (3 – 5.5 mm). The inner diameter of the pipes changed within a range from 146.5 to 149 mm.

The basic sizes, static characteristics and mass of circular section pipes calculated are given in Table 1.

Table 1. The sizes, static characteristics and mass of a one meter long pipe.

Sizes of a pipe, mm		Cross-section area F, cm^2	Static characteristics for axes x and y		Mass of a one meter long pipe M, kg
Outer diameter, D	Wall width, S		Inertia moment of the section, cm^4	Modulus of section, cm^3	
152	3.0	14.04	389.87	51.30	11.02
	3.2	14.96	414.21	54.50	11.74
	3.5	16.33	450.35	59.26	12.82
	3.8	17.69	486.04	63.95	13.89
	4.0	18.60	509.59	67.05	14.60
	4.5	20.85	567.61	74.69	16.37
	5.0	23.09	624.43	82.16	18.13
	5.5	25.31	680.06	89.48	19.87

In order to optimize the tank container structure, spatial meta-models were built in SolidWorks software [14], the strength calculation was made with the finite element method [15-18]. The results of the research conducted are given in Table 2.

Table 2. The results of the strength calculation for the spatial models

Outer diameter D, mm	Wall width, mm	Stresses, MPa	Mass, kg	Deformations
152	3.0	318.32	1055.61	$1.701 \cdot 10^{-3}$
	3.2	316.466	1061.69	$1.726 \cdot 10^{-3}$
	3.5	315.482	1070.77	$1.758 \cdot 10^{-3}$
	3.8	314.525	1057.39	$1.790 \cdot 10^{-3}$
	4.0	313.639	1063.38	$1.858 \cdot 10^{-3}$
	4.5	311.555	1078.33	$1.927 \cdot 10^{-3}$
	5.0	311.664	1093.17	$1.948 \cdot 10^{-3}$
	5.5	310.8	1093.17	$1.983 \cdot 10^{-3}$
	5.5[1]	316.374	1075.17	$1.868 \cdot 10^{-3}$

[1] it is taken that the pipe has cross section along the whole vertical post for the tank container

To obtain the optimal frame structure (optimal structural geometric parameters of pipe sections to be used), the optimization research was made in the

following order: it was determined that optimization be made by the minimal material capacity criterion (m) with meeting the strength requirements (without exceeding the admissible stress values σ); on the basis of structural features, the limits at which variable values could change, i.e. the outer diameter of the pipe (D) and the wall width (S) were determined; it was determined that mathematical models of parametric variations (m, σ, l) were described with two-factor generalized mathematical models which were defined through nine experiments based on the corresponding spatial computer models; and the mathematical models were determined, on the basis of which an additional schedule was built and optimal geometrical parameters of pipes were defined.

At the first stage, the decision was taken to use a circular pipe along the whole height of the vertical post of the tank container. The results of the strength calculation demonstrated that stresses in the contact area between the support and the vertical post did not exceed the admissible values for the steel grade of the metal structure of the tank container. Therefore, while building a spatial computer model of the tank container it was considered that the vertical post of circular section was located on the special superstructure (Fig. 2) in the form of a truncated pyramid. In order to decrease the impact loads between the fittings of the container and the fitting stops of the flat wagon under shunting impacts, when the impact loads exceeded the friction force between the horizontal planes of the fittings and fitting stops, the authors filled the fitting stops with elastic (Fig. 3, a) or viscoelastic (Fig. 3, b) materials of dumping or anti-corrosion properties.

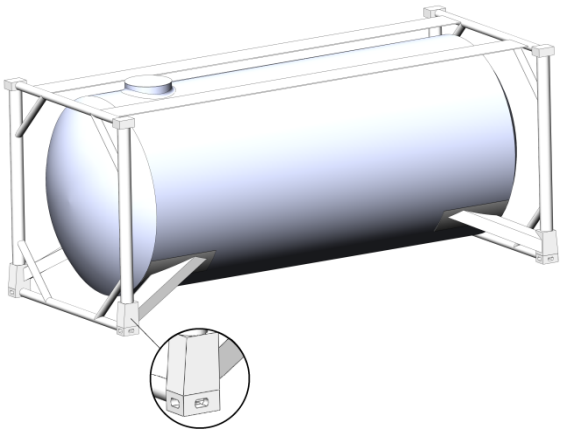


Fig. 2. The spatial model of an improved tank container.

Using the factor values obtained (m, σ, l), the authors approximated them in the form of second-order polynomials:

$$Y = f(x_{t_1}, x_{t_2}, x_{t_3}, x_{t_a}) = a_0 + a_1 x_{t_1} + a_2 x_{t_2} + a_3 x_{t_3} + a_4 x_{t_a} + a_{11} x_{t_1}^2 + a_{11} x_{t_1}^2 + a_{22} x_{t_2}^2 + a_{33} x_{t_3}^2 + a_{44} x_{t_a}^2 + a_{12} x_{t_1} x_{t_2} + a_{13} x_{t_1} x_{t_3} + a_{14} x_{t_1} x_{t_a} + a_{23} x_{t_2} x_{t_3} + a_{24} x_{t_2} x_{t_a} + a_{34} x_{t_3} x_{t_a}, \quad (1)$$

where Y – the controlled value, x_{t_a} – the control parameters, a_i – the coefficients of a generalized mathematical model, the numeric values of which were defined through solving an equation system with the data obtained.

Generalized mathematical models and an additional schedule for the optimal pipe parameters of the tank container's frame were developed in a software suite.

The generalized mathematical models obtained have the following form:

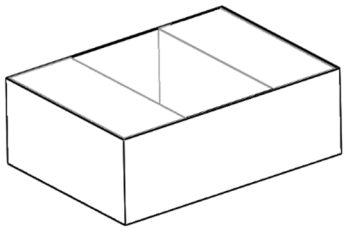
$$m = -70130 + 924.3D + 542.416S - 3D^2 + 2.048S^2 - 3.6DS, \quad (2)$$

$$s = 22383.3 - 286.18D - 181.77S + 0.928858D^2 + 1.1853S^2 + 1.1146DS, \quad (3)$$

$$l = -0.4537 + 0.00591D + 0.0038S - 1.916D^2 - 0.000023S^2 - 0.00002DS, \quad (4)$$

where D – the outer diameter of the pipe, mm, S – the pipe wall width, mm, m – the structure mass, kg, l – the deformations in the structure, σ – the stresses in the structure, MPa.

(a)



(b)

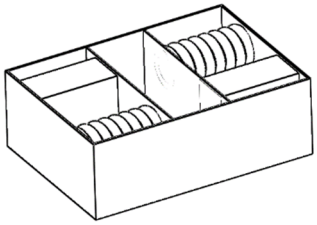


Fig. 3. The fittings of the tank container: (a) with viscous linkage, (b) with viscoelastic linkage.

The mathematic model verification (2 – 4) was made by the mean square error value [19, 20]:

$$\sigma = \sqrt{\frac{\sum_{j=1}^{m-k}(Y_j - Y_{jp})^2}{m-k}}, \quad (5)$$

where k – the number of coefficients a_i of the generalized mathematical model; m – the number of mathematic modes.

The calculations conducted confirmed the efficiency of the generalized mathematical models obtained [21-23]. And the mean square error value did not exceed 3%.

In order to decrease the impact loads between fittings of the container and fitting stops of the flat wagon under shunting impacts, when the dynamic load P_d exceeds the friction force F_{FR} between horizontal planes of fittings and fitting stops, the authors suggest installing viscous or viscoelastic elements in the fittings of the container.

In order to define the dynamic loading of the container in shunting impacts considering the improvements, a mathematical model (6) was built; the model took into account displacements of the container placed on the flat wagon.

$$\begin{cases} M_{FC}^{gw} \cdot \ddot{q}_1 = P_l - \sum_{i=1}^{n} \left(F_{FR} \cdot sign(\dot{q}_1 - \dot{q}_2) + \beta_v (\dot{q}_1 - \dot{q}_2) \right), \\ M_C \cdot \ddot{q}_2 = \sum_{i=1}^{n} (F_{FR} \cdot sign(\dot{q}_1 - \dot{q}_2) + \beta_v (\dot{q}_1 - \dot{q}_2) + \\ + M_M \cdot l \cdot q_3), \\ I_m \cdot \ddot{q}_3 = M_M \cdot l \cdot \ddot{q}_2 - g \cdot M_M \cdot l \cdot q_3, \end{cases} \quad (6)$$

where M_{FC}^{gw} – the gross weight of a flat wagon; P_l – the value of longitudinal force on the automatic coupling; F_{FR} – the friction force between fitting stops and fittings; M_C – the tank container mass; β_v – the viscous resistance coefficient in the container's fittings; M_M – the mass of the pendulum imitating displacements of bulked cargo in the tank container; l – the length of the pendulum suspension; I_m – the inertia moment of the pendulum; q_1, q_2, q_3 – the coordinates indicating displacements of flat wagon, tank container and bulked cargo, respectively, relative to the longitudinal axis.

At the given viscous resistance in the container's fittings, the acceleration was approximately 40 m/sec^2 (≈ 4 g) and did not exceed the normalized value [24].

Besides, the total viscous resistance to displacements of one tank container should be within a range from 9 to 54 kN·sec/m.

At viscoelastic linkage between fittings and fitting stops, the mathematical model has the form:

$$\begin{cases} M_{FC}^{gw} \cdot \ddot{q}_1 = P_l - \sum_{i=1}^{n} (F_{FR} \cdot sign(\dot{q}_1 - \dot{q}_2) + C_v (q_1 - q_2) + \\ + \beta_v (\dot{q}_1 - \dot{q}_2), \\ M_C \cdot \ddot{q}_2 = \sum_{i=1}^{n} (F_{FR} \cdot sign(\dot{q}_1 - \dot{q}_2) + C_v (q_1 - q_2) + \\ + \beta_v (\dot{q}_1 - \dot{q}_2) + M_M \cdot l \cdot q_3), \\ I_m \cdot \ddot{q}_3 = M_M \cdot l \cdot \ddot{q}_2 - g \cdot M_M \cdot l \cdot q_3, \end{cases} \quad (7)$$

where C_v – the rigidity of the elastic elements in the tank container's fittings.

The rigidity of an elastic element was taken 480 kN/m, and the viscous resistance coefficient – 30 kN·sec/m. The maximum acceleration was about 40 m/sec^2 (≈ 4 g) and did not exceed the normalized value.

The acceleration values obtained were considered in strength calculations for the tank container.

The strength calculation was made with the finite element method in SolidWorks software suite [25-27]. When designing the finite element model of the tank container, isoparametrical tetrahedrons were used; the optimal number of them was determined with the grapho-analytical method.

The basic characteristics of the finite-element model for the optimized tank container are given in Table 3.

Table 3. The basic characteristics of the finite-element method of the optimized tank container

Parameter	Value
The number of Jacobian points	4
The number of units	376555
The number of elements	1162350
The maximum size of an element, mm	20
The minimum size of an element, mm	4
The minimum number of elements in a circle	10
Ratio of an element size expansion	1.7
Maximum side ratio	177.52
Percent of elements with a side ratio less than 3	36.7
Percent of elements with a side ratio more than 10	0.939

While designing the strength model for the tank container, it was considered that the structure was effected by vertical static loads P_v^{st}, pressure of bulked cargo P_p, longitudinal pressure on the bottom P_l, horizontal pressure on the fitting stop P_{hp} conditioned by the force P_n, and vertical load on the fitting P_v conditioned by P_v^{st} (Fig. 4).

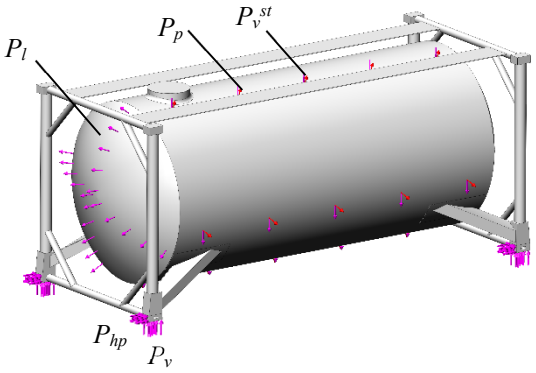


Fig. 4. The design diagram of the tank container.

The tank container was fixed in the areas where the flat wagon rested on fitting stops. The 09G2C steel was used as a construction material.

The maximum equivalent stresses were 294.1 MPa (Fig. 5, 6). The maximum displacements were concentrated in the area of the access door and accounted for 7.24 mm (Fig. 7, 8), the maximum deformations were $2.79 \cdot 10^{-3}$ (Fig. 9, 10).

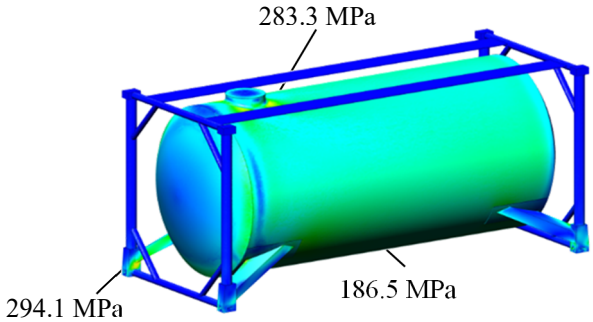


Fig. 5. Stressed state of the tank container.

Thus, the research conducted confirmed the efficiency of decisions taken during designing the tank container.

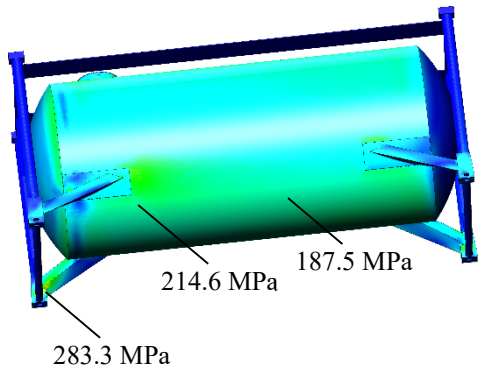


Fig. 6. Stressed state of the tank container (bottom view).

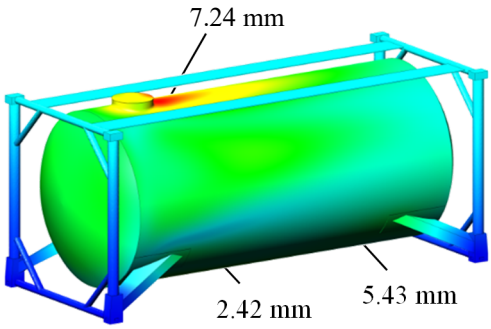


Fig. 7. Displacements in the tank container.

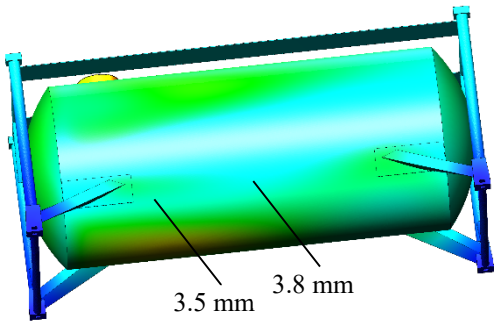


Fig. 8. Displacements in the tank container (bottom view).

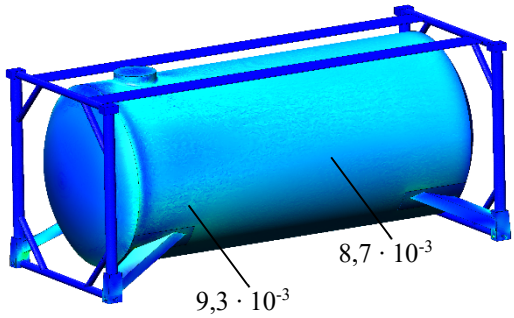


Fig. 9. The deformations in the tank container.

4 Conclusions

The following conclusions can be made on the basis of the research:

1. The carrying structure of the tank container was optimized with circular pipes for the frame. The vertical post of the frame was located on the special superstructure in the form of a truncated pyramid. It was determined that the mass of the optimized frame was less than that of a typical one by about 20%;

2. In order to decrease the impact loads between the fittings of the container and fitting stops of the flat wagon under shunting impacts, when the impact loads exceeded the friction force between the horizontal planes of fittings and fitting stops, the authors suggested filling fitting stops with elastic or viscoelastic materials of dumping or anti-corrosion properties.

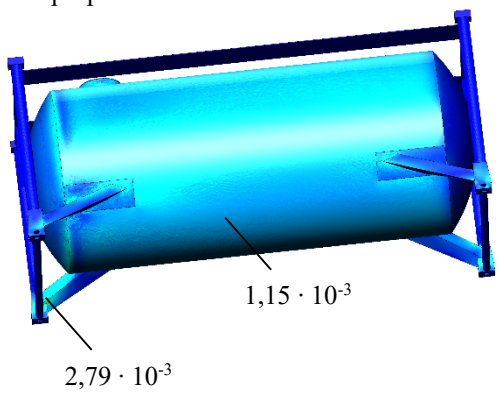


Fig. 10. The deformations in the tank container (bottom view).

The optimized structure of the tank container was calculated for strength. The maximum equivalent stresses were 294.1 MPa. The maximum displacements were concentrated in the area of an access door and accounted for 7.24 mm, the maximum deformations were $2.79 \cdot 10^{-3}$. The research conducted will promote designing new-generation tank containers, thus improving the efficiency of rail transportation along international transport corridors.

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Formation of flash-concept for a resource-saving articulated hopper car to transport hot pellets and agglomerate

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Abstract. Higher operational efficiency of hopper cars can be achieved with the flash-concept for a resource-saving structure. The characteristic feature such cars is the use of circular pipes as the carrying body elements. The engineering solution made it possible to decrease the tare weight of a hopper car in comparison with that of a prototype by 5%. A 20-9749 hopper car, manufactured by Panutinskiy Car Repair Plant (Ukraine), was taken as a prototype. On the basis of the suggested hopper car, an articulated car was designed. The dynamic loading of the articulated hopper car was defined with mathematical modelling. The study was conducted in plane coordinates. The acceleration values obtained were considered in the strength calculation for the carrying structure of the hopper car. The strength factors were defined in COSMOSWorks software environment. It was determined that the maximum equivalent stresses in elements of the carrying structure did not exceed the admissible values. The results of the research will promote designing innovative hopper cars for transporting hot pellets and agglomerate, thus enhancing higher efficiency of rail transportation.

1 Introduction

An intense competitive environment in the transport industry requires designing innovative rail transport facilities to maintain a leading position for rail transportation. And particular attention should be given to the carrying structural elements of cars as they constitute a greater part of the tare weight.

Thus, hopper cars have found a wide application for transporting hot pellets and agglomerate at production enterprises. A characteristic of these cars is their sheath which is not welded to the body frame, but hangs on it; the front walls are inclined, which allows the discharge by means of gravity [1]. The carrying structure of a railcar transporting pellets is under constant working and temperature loads from the cargo. Therefore, there is a need to improve the existing structure of a hopper car to provide an appropriate strength and improve the operational efficiency.

2 Analysis of recent researches

Improvements in the carrying structure of a 19-9862 hopper car for ensuring the required strength under working loads are described in [2]. The study puts forward some ideas about how to strengthen the assembly unit which connects the end vertical and middle inclined posts with a lateral angle bar of the inclined end wall of a hopper car. The strength calculation is made in DSMFem software package. The results of the calculation confirm the efficiency of the solutions proposed.

A longer service life of hopper railcars is substantiated in [3]. The study gives a general overhaul schedule which provides for a longer service life of railcars. The research is made by an example of a 19-6930 hopper car.

However, the authors do not consider improvements in the carrying structure of a hopper cars used for transporting hot pellets and agglomerate.

The innovation structure of a hopper car developed by the Greenbrier Companies is featured in [4]. The body cubic capacity of the car is 146 m^3. The car body can automatically be discharged in 30 seconds. Besides, the speed of unloading commodities can be regulated.

However, the company has not considered problems of designing hopper cars for transporting hot pellets and agglomerate.

Some design features of prospective freight car structures are presented in [5]. The study gives requirements for designing the carrying structures of railcar at the modern stage of rail industry development. But the author does not consider improvements in the carrying structure of a hopper car and ways to increase the operational efficiency.

Development of prospective structures of freight cars is highlighted in [6, 7]. The studies give spatial models of carrying structures of railcars and their strength calculations.

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However, designing resource-saving structures of hopper cars for transporting hot pellets and agglomerate is not covered in the research.

The designing of a freight car body of composite panels is given in [8]. The authors suggest the use of anticorrosive materials for paint-and-lacquer coating of a car. But modernization of hopper cars for transporting hot pellets is not considered in the study.

The purpose of the article. The purpose of the article is to highlight the flash-concept formation for a recourse-saving articulated hopper car for transporting hot pellets and agglomerate.

3 Results and discussion

A prospective area in achieving the purpose of the study is creation of the functional-adaptive flash-concept of a railcar by the results of adequate mathematical and computer modelling.

The flash-concept is understood as the technical image of a prospective railcar, intended for theoretical and structural representation of the operational principles.

The authors suggest the use of circular pipes as carrying elements to decrease the tare weight of a hopper car for transporting hot pellets and agglomerate. This engineering solution makes it possible to decrease the tare weight of a hopper car in comparison with that of a prototype (Model 20-9749) by 5%.

On the basis of the designed structure of a hopper car, an articulated railcar was developed (Fig. 1, 2). The solution may increase the operational efficiency of the car and decrease the production costs in comparison with that of a four-axle car.

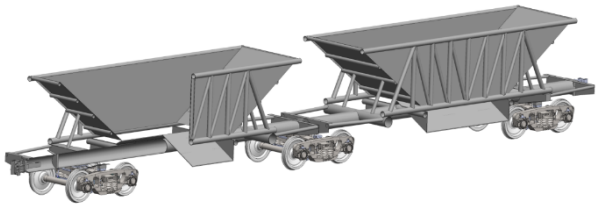

Fig. 1. An articulated hopper car for transporting hot pellets and agglomerate

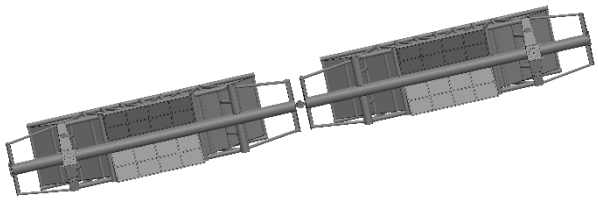

Fig. 2. An articulated hopper car for transporting hot pellets and agglomerate (bottom view).

It should be mentioned that there are articulated hopper cars manufactured by Research and Production Corporation “United Wagon Company” (RPC UWC) (Fig. 3 [9]). However, the company has not designed articulated hopper cars for transporting hot pellets and agglomerate.

Fig. 3. An articulated hopper car.

While developing the flash-concept of an articulated hopper car, the authors replaced the bolster beam, where it rested on the middle running gear, for a circular section beam (Fig. 4).

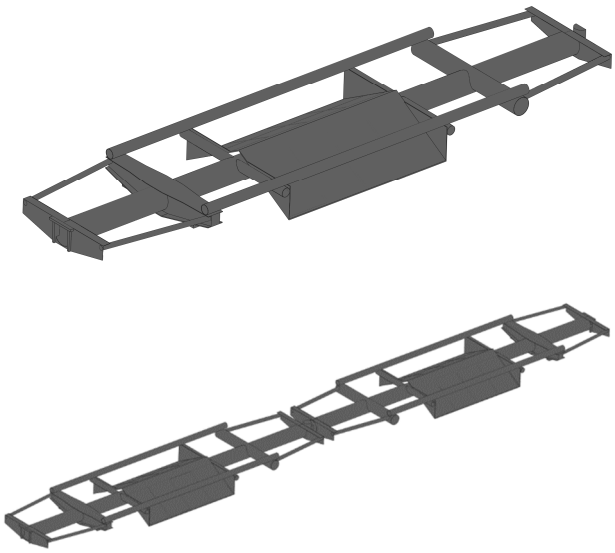

Fig. 4. The frame of an articulated hopper car.

The dynamic loading on the carrying structure of a hopper car at the least favorable operational mode (jerk) was defined with a mathematical model, it was designed by prof. Bogomaz for a long-base flat wagon loaded with tank containers. The model was improved by the authors of the article and considered displacements of two interacting sections of the articulated hopper car.

$$M'_{C_1} \cdot \ddot{x}_{C_1} + M_{C_1} \cdot h \cdot \ddot{\varphi}_{C_1} + k'\left(x_{C_1} - x_{C_2}\right) = P_1, \qquad (1)$$

$$I_{C_1}\cdot\ddot{\varphi}_{C_1}+M_{C_1}\cdot h\cdot\ddot{x}_{C_1}-g\cdot\varphi_{C_1}\cdot M_{C_1}\cdot h= \\ =l\cdot F_{FR}\left(sign\dot{\Delta}_1^{C_1}-sign\dot{\Delta}_2^{C_1}\right)+ \\ +l\left(k_1\cdot\dot{\Delta}_1^{C_1}-k_2\cdot\dot{\Delta}_2^{C_1}\right), \quad (2)$$

$$M_{C_1}\cdot\ddot{z}_{C_1}=k_1\cdot\Delta_1^{C_1}+k_2\cdot\Delta_2^{C_1}-F_{FR}\left(sign\dot{\Delta}_1^{C_1}-sign\dot{\Delta}_2^{C_1}\right), \quad (3)$$

$$M'_{C_2}\cdot\ddot{x}_{C_2}+M_{C2}\cdot h\cdot\ddot{\varphi}_{C_2}-k'\left(x_{C_1}-x_{C_2}\right)=0, \quad (4)$$

$$I_{C_2}\cdot\ddot{\varphi}_{C_2}+M_{C_2}\cdot h\cdot\ddot{x}_{C_2}-g\cdot\varphi_{C_2}\cdot M_{C2}\cdot h= \\ =l\cdot F_{FR}\left(sign\dot{\Delta}_1^{C_2}-sign\dot{\Delta}_2^{C_2}\right)+l\left(k_1\cdot\dot{\Delta}_1^{C_2}-k_2\cdot\dot{\Delta}_2^{C_2}\right), \quad (5)$$

$$M_{C_2}\cdot\ddot{z}_{C_2}=k_1\cdot\Delta_1^{C_2}+k_2\cdot\Delta_2^{C_2}-F_{FR}\left(sign\dot{\Delta}_1^{C_2}-sign\dot{\Delta}_2^{C_2}\right), \quad (6)$$

where

$$\Delta_1^i=z_{C_i}-l\cdot\varphi_{C_i}\ ;\ \Delta_2^i=z_{C_i}+l\cdot\varphi_{C_i} \quad (7)$$

M'_{C_i} – the gross weight of the *i*-th section; M_{C_i} – the mass of the carrying structure of the *i*-th section; I_{C_i} – the inertia moment of the *i*-th section; P_l – the value of longitudinal force on the automatic coupling; F_{FR} – the absolute value of dry friction in a spring group; k' – the linkage rigidity between sections; k_1, k_2 – the spring rigidity of bogies' spring groups; x_i, φ_i, z_i – the coordinates indicating displacements of car sections relative to the corresponding axes.

Besides, jerking (1), (4), bouncing (2), (5) and galloping (3), (6) oscillations were taken into account. The design diagram is given in Fig. 5.

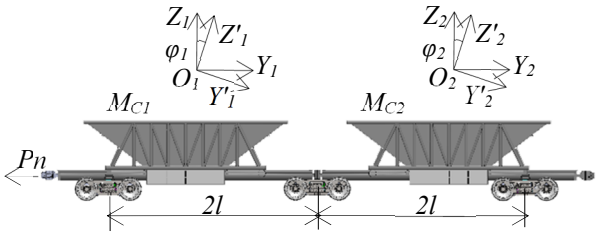

Fig. 5. The design diagram of an articulated hopper car.

The articulator was designed by means of elastic linkage. The value of longitudinal force on the front support of the automatic coupling of a car section was 2.5 MN [10, 11]. It was also considered that the car rested on three 18-100 bogies.

As the axial load of wheelsets of this bogie was 23.5 t/axle (230.535 kN/axle), the gross weight of the car should not exceed 1,383.21 kN. It should be mentioned that bogies of increased axial loads can be used under the car.

The differential equations were solved in MathCad software suite [12, 13]. The initial displacements and speeds were taken equal to zero [14-16].

It was established that maximum acceleration on a first section (from the side where the longitudinal force was applied) accounted for 31.4 m/sec^2, and on a second section – 32.3 m/sec^2.

The acceleration values obtained were considered in the strength calculation for the carrying structure of a hopper car as constituents of the dynamic loading.

The strength calculation was made by the finite element method [17-20] in COSMOSWorks software suite.

The authors of the article developed a design diagram of the carrying structure of a hopper car (Fig. 6, 7). It allowed for the vertical static load P_v^{st}, the lateral pressure P_p on the body walls, and also the longitudinal load P_l on the front support of an automatic coupling.

The model was fixed in the areas where it rested on the running gears. The basic carrying elements of the car body were made of Steel grade 09G2S. The movable car lining of higher resistance properties could compensate a heat expansion.

Isoparametric tetrahedrons were used in designing the finite-element model [21-24].

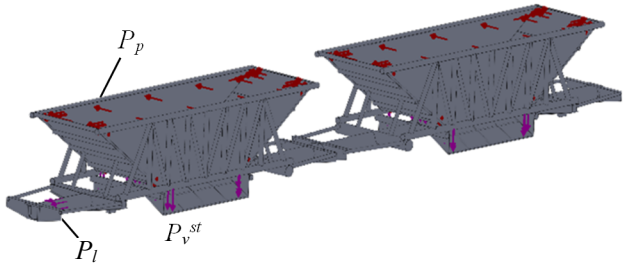

Fig. 6. The design diagram of the carrying structure of a hopper car.

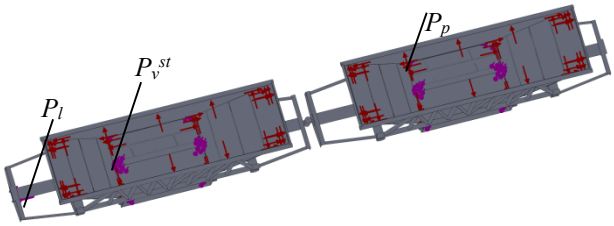

Fig. 7. The design diagram of the carrying structure of a hopper car (bottom view).

The basic characteristics of the finite element model are given in Table 1.

Table 1. The basic characteristics of the finite-element model of the carrying structure of an articulated hopper car

Parameter	Value
The number of Jacobian points	4
The number of units	1590958
The number of elements	4845516
The maximum size of an element, mm	20
The minimum size of an element, mm	4
The minimum number of elements in the circle	10
Ratio of an element size expansion	1.8
The maximum side ratio	773.8
Percent of elements with the side ratio less than 3	73.6
Percent of elements with the side ratio more than 10	3.36

The results of the calculations are given below (Fig. 8 – 14).

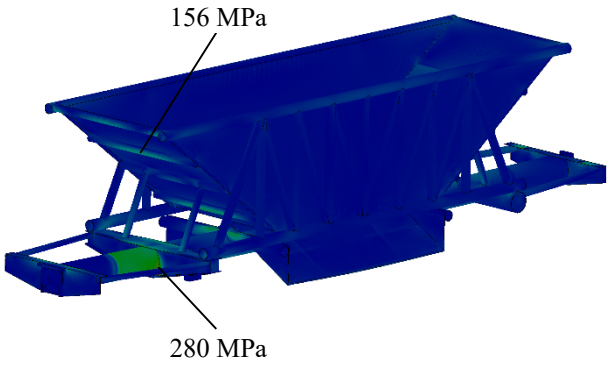

Fig. 8. The stressed state of the section of an articulated hopper car.

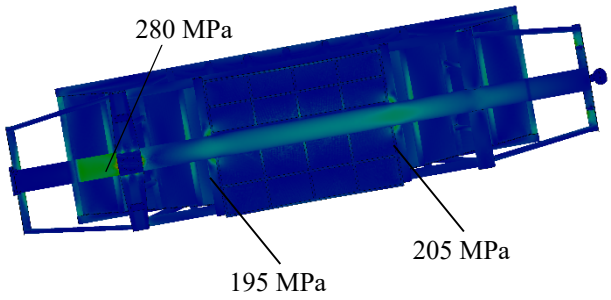

Fig. 9. The stressed state of the section of an articulated hopper car (bottom view).

The distribution of the maximum equivalent stresses along the center sill of the section of the hopper car is given in Fig. 10.

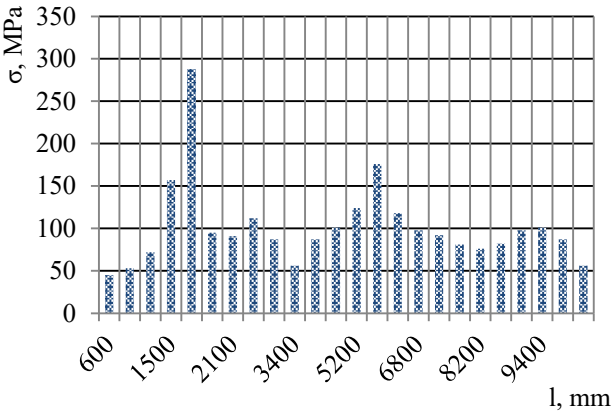

Fig. 10. The distribution of stresses along the bolster beam of a hopper car section.

And the maximum equivalent stresses emerged in the zone of interaction between the center sill and the bolster beam and were about 280 MPa, i.e. they did not exceed the admissible values [10, 11, 25].

The maximum displacements were 5.6 mm (Fig. 11, 12); they were concentrated in the discharge hoppers. The maximum deformations were 5.8 10^{-5} (Fig. 13, 14).

The temperature impact of the car body was not calculated as the lining sheets of the walls and hoppers were not changed.

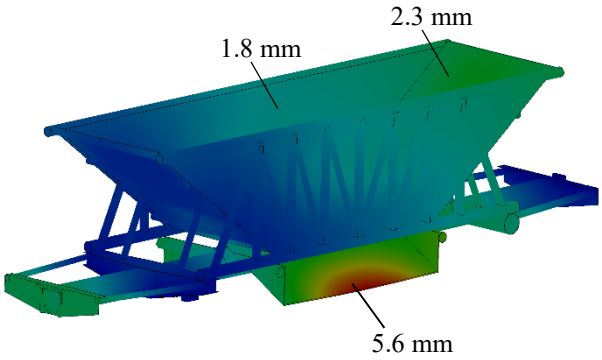

Fig. 11. The displacements in the section units of an articulated hopper car.

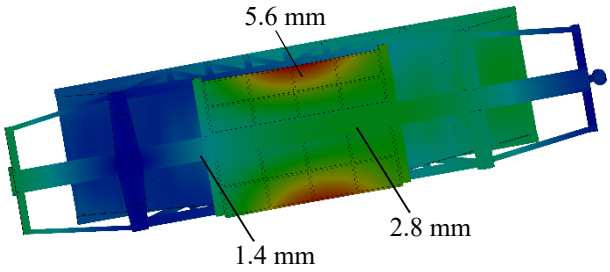

Fig. 12. The displacements in the section units of an articulated hopper car (bottom view).

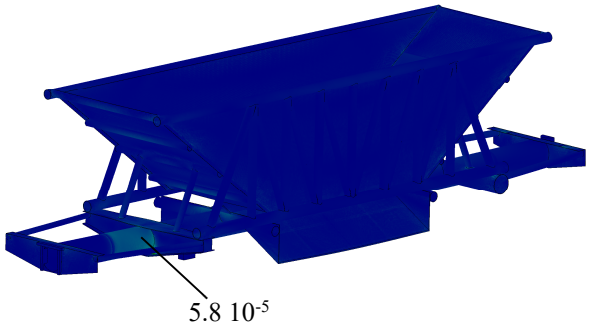

Fig. 13. The deformations in the section units of an articulated hopper car.

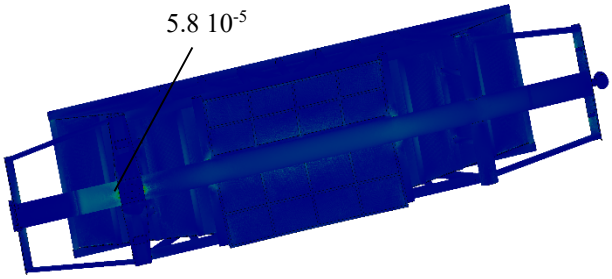

Fig. 14. The deformations in the section units of an articulated hopper car (bottom view).

Besides, the authors conducted a modal analysis of the carrying structure of a hopper car [26, 27] and defined the critical frequencies of oscillations (Table 2).

The results obtained made it possible to conclude that values of the critical frequencies of oscillations were within the admissible range.

Besides, the study presents the calculation of a design service life of a railcar [28-30]

$$T_n = \frac{\left(\sigma_{-1L} / [n]\right)^m \cdot N_0}{B \cdot f_e \cdot \sigma_a^m}, \quad (8)$$

where σ_{-1L} – the average value of the endurance limit, MPa; n – the admissible coefficient of the strength factor; m – the exponent of the fatigue curve; N_0 – the testing base; B – the coefficient indicating a period of continuous run of the object in seconds f_e – the efficient frequency of dynamic stresses, Hz; σ_a – the amplitude of equivalent dynamic stresses, MPa.

Table 2. The numerical values of the critical frequencies of oscillations for the carrying structure of an articulated hopper car.

Type of oscillations	Frequency, Hz	Period, from
1	10.434	0.096
2	12.378	0.081
3	13.076	0.076
4	15.67	0.064
5	17.572	0.057
6	18.238	0.055
7	21.125	0.047
8	27.431	0.036
9	27.978	0.036
10	28.315	0.035

The coefficient characterizing a period of continuous run of the object was determined as follows

$$B = \frac{365 \cdot 10^3 \cdot L_c}{\vartheta_{av}(1+0.34)}, \quad (9)$$

where L_c – the average daily car run, km; ϑ_{av} – the average value of the car speed, m/sec; 0.34 – the empty run coefficient.

The efficient frequency of dynamic stresses was defined as follows

$$f_e = \frac{1{,}1}{2\pi}\sqrt{\frac{g}{f_{st}}}, \quad (10)$$

where f_{st} – the static deflection of a spring group, mm.

The following input parameters were taken in the research: the average endurance limit was defined as $0.5\sigma_в$ of the material (Steel grade 09G2C) and accounted for 245 MPa; the testing base was 10^7 cycles (recommended for steel); the period of continuous run of the object was 6,514.37 sec; the efficient frequency of dynamic stresses considered the spring suspension parameters of a 18–100 bogie and accounted for 2.7 Hz; the admissible strength factor was taken equal to 2; the fatigue curve exponent for a welded structure equaled to 4; and the amplitude of equivalent dynamic stresses was 67.3 MPa.

On the basis of the calculation it was established that a design service life of the carrying structure of an articulated car is more than 32 years.

4 Conclusions

The following conclusions were drawn from the research:

1. The flash-concept of an articulated hopper car for transporting hot pellets and agglomerate was created. A characteristic of the car is the use of circular pipes as the carrying elements of the body. The engineering solution made it possible to decrease the tare weight of the carrying structure of a hopper car in comparison with that of a prototype (Model 20-9749) by 5%.
2. The dynamic loading of a hopper car for transporting hot pellets and agglomerate was determined. It was determined, that the maximum acceleration on a first section (from the side where the longitudinal force was applied) accounted for 31.4 m/sec^2, and on a second section – 32.3 m/sec^2.
3. The strength values for an articulated hopper car intended for transporting hot pellets and agglomerate were defined.

The maximum equivalent stresses emerging in the carrying structure of an articulated hopper car section were about 280 MPa, i.e. they did not exceed the admissible values. The maximum displacements accounted for 5.6 mm and were concentrated in the discharge hoppers. The maximum deformations were $5.8 \cdot 10^{-5}$.

The results of the research will promote designing modern hopper cars for transporting hot pellets and agglomerate, thus increasing the rail transportation efficiency.

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Determination of parameters of abnormal wear of brake pads of freight cars

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Abstract. The complex of operational studies and theoretical research was performed on the occurrence of harmful wear that changes geometrical parameters of the useful contact area of the brake pads of freight cars at various established standard clearance between the pad and the wheel, which significantly impairs the braking efficiency of trains. The inspections of the mechanical part of the brakes attracted attention to the abnormal wear of the brake pads of the freight cars, which occurs because the common centre of gravity of the pad and the brake shoe, which are on the pendular suspension, do not coincide with the centre of the hole in the brake strut for any pad. The results of calculations using the coordinate method performed in the Mathcad software environment and the graphical one performed in AutoCAD to determine the geometrical parameters of the formation of the upper harmful wear of the pad depending on the standard clearance between the wheel and the brake pad were compared to proved theoretically that the error between them does not exceed 5-7%.

1 Introduction

As the speed of movement and axial loads during transportation of goods at Ukrzaliznytsya JSC have been increasing, as well as the periods between repairs of the brake system of freight cars should be extended, a number of new design solutions have been applied to ensure the normal wear of brake pads. However, some of the proposed solutions have proven to be ineffective, so the issue of abnormal wear of brake pad remains in abeyance [1].

To scientifically substantiate the innovations that ensure the prolongation of the safe operation of the brake pads, we have summarized the material of a few studies which search for the ways to slow down the wear of brake pads of freight cars in Ukrzaliznytsia JSC.

2 Analysis of the latest achievements

Multiple studies have been devoted to the investigation of causes and effects of this negative phenomenon. In particular, [2] describes a device used in the brake rigging (BR) of bogies to retract the pads with automatic adjustment of their relative position with respect to the rolling surfaces of the wheels. However, it is important to note that such a device complicates the BR design of the bogie and requires systematic labour-intensive adjustments during the operation, hence, using it is impractical.

In [3], the stresses occurring in the brake pad were analyzed, the thermal analysis was performed using the SolidWorks software and an alternative solution life was suggested to improve the brake pad material and prolong the service life.

The authors in article [4] refer to various friction brake systems used in mechanical braking. It is noted that friction brake systems in which brake pads are used have adverse effect on the rolling surface of the wheels, as high temperatures occur in the "pad-wheel" friction zone, so disc brakes are preferred.

Foreign researchers are focused on the study of disc brakes, strength calculations of their elements, real-time observations of their operation, and also on the calculations of the temperature conditions of some elements of the brake systems of rolling stock [5, 6]. When a train is braked with friction brakes, thermal energy is generated in the contact area of tribotechnical bodies, which is dissipated by forced convection, conduction, and radiation from the open surfaces of the brake.

Papers [7, 8] state that overheating of tribotechnical pairs can cause malfunction of the brake system and compromise the safety of movement. Therefore, considerable theoretical work is being done considering the elevation of temperature during braking for different speeds of movement and brake disc design.

Considering the analyzed literature sources, it should be noted that the problems of abnormal wear of the brake pads used in the brake systems of three-element bogies have not received sufficient attention yet.

3 Purpose and tasks of the study

The purpose of this study is determining the geometrical

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parameters of the brake pads of freight cars in case of harmful wear.

To achieve the stated purpose, the following tasks must be solved:

– performing analysis of the causes of the upper harmful wear which changes geometrical parameters of the useful contact area of the brake pads and occurs during train movement in traction and run modes;

– developing a methodology for determining the geometrical parameters of the upper harmful wear of the pad depending on the standard clearance between the wheel and the brake pad to improve the braking efficiency of trains;

– plotting graphical dependencies according to the developed methodology: lengths of harmful wear of the brake pad on its horizontal wear; harmful area and the amount of wear of the pad on the amount of uneven wear depending on the clearance between the wheel and the pad to determine the geometrical parameters of the useful contact area of the pad;

– proposing techniques to eliminate the upper harmful attrition which causes abnormal wear of the brake pads during the movement of freight cars and significantly impairs the braking efficiency of trains.

4 Results and discussion

The results of inspections of the mechanical part of the brakes in the bogies of freight car demonstrated that some brake pads which had abnormal wear had been re-installed in the car and already turned so that the harmful wear was at the bottom and the upper parts of the pads were intact. It should be noted that in accordance with the requirements of current regulatory and technological documents, turning brake pads is not recommended [9].

However, some workers in maintenance depot turn brake pads that were removed during the current repair or overhaul of the cars, claiming that this would equalize their wear and tear. The reason for it is the fact that the number of new pads is insufficient to replace the faulty pads in operation and the workers have to use the brake pads previously removed from the cars during the repairs turning them by 180^0 (Fig. 1) for the subsequent operation of the freight cars.

Such actions are the reason why braking efficiency significantly deteriorates in the freight trains and multiple malfunctions of rolling surfaces of wheel pairs occur during the operation of such brake pads, which damage the railway infrastructure [10, 11].

Therefore, it should be noted that a violation of the instructions can lead to grave consequences on the railway, such as smash-ups, traffic accidents, and mishaps, etc., which is a direct threat to the safety of railway traffic. For this reason, conditions and devices should be developed to ensure that the brake pads in the bogies of freight cars are worn out evenly. As a consequence, first, they can be used within the entire period between depot repairs; second, the railway companies will save tens of thousands of hryvnias for the procurement of pads; and third, brake pads will be disposed of with only insignificant amount of the remaining working composite mass [12].

Fig. 1. View of a dual wedge-worn brake pad in operation.

Naturally, when the car is braked during the movement, friction occurs between the rolling surface of the wheel and the working surface of the brake pad causing friction wear. However, during the inspections of 16,640 pads in the freight cars of the operated fleet in maintenance depots, it was found that most of the pads are bent when the brake is released, their upper edges touch the rolling surface of the wheels and make friction during the movement. When the length of the harmful wear of the pad that reduces the useful area and affects the braking process was measured, it was found that it can take up to 150 mm of the total length of the pad (Fig. 2, a).

It should also be noted that two wear surfaces are formed on the pads: the upper one is where the pad is worn obliquely symmetrically as cars move without braking, quite intensively depending on the speed of movement; and the lower one which is used to brake the car.

In bogie BR of freight cars, the point of connection of the vertical levers with the brake strut is shifted towards the wheel relative to the points of connection of the triangle shoe with the pendulum suspension. This causes touching by the upper part of the pad of the wheel rim when the brakes are released (Fig. 2, b). As a result, a significantly thick wear of the top of the pad occurs, and consequently, the length of its working surface is reduced.

Studies have shown that the smaller the retraction distance of the pad from the wheel and the angle between the surface of the wheel rim and the working part of the pad is, the greater the length is which begins from the upper end of the pad and is subjected to wear when the brake is released.

However, it should be noted that, if a clearance is excessive, it is generally larger at the bottom of the pad (Fig. 2, c) than at the top, intensive wear occurs at the upper edge of the pad.

Fig. 2. Pictures of the wedge dual wear of the brake pad in operation: a – measurement of the length of harmful wear; b – interaction of the upper end with the rolling surface of the wheel during movement of the car; c – abnormal clearance between the pad and the wheel.

4.1 Determination of geometrical parameters of the length of the harmful wear at the top of the brake pad with known wear at the top

Design diagram of rotation of the brake pad with a shoe is shown in Fig. 3.

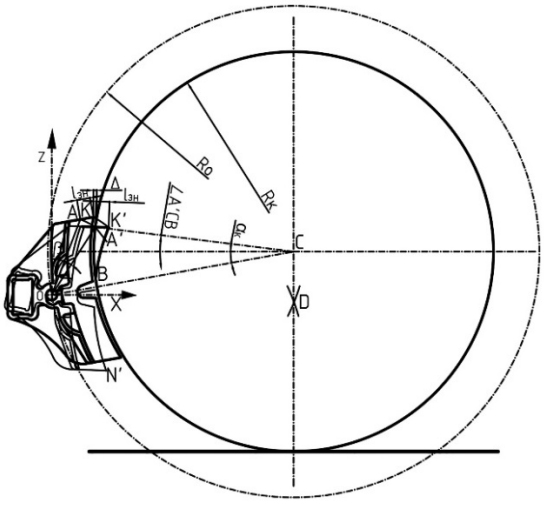

Fig. 3. Design diagram of rotation of the shoe with the pad.

The task is reduced to determination of the length of arc $\cup A'B$, which can be calculated according to the following formula [13]

$$\cup A'B = \frac{\pi R \cdot \angle A'CB}{180}, \quad (1)$$

where R is the estimated radius of the car wheel, m.

Let us denote the coordinate system at point O. Axis Z is selected as vertical, and axis X is selected as horizontal, as it is customary in car designing.

Calculations are performed using the coordinate method. First, the coordinates of point A' are calculated that is the point of intersection of the circle with the centre at point O and radius $OA = OA'$ and circles with the centre at point C and radius R.

The equation for the circle with the centre at point O and radius OA will be as follows

$$x^2 + z^2 = OA^2, \quad (2)$$

Relative to the circle with the centre in point C

$$(x - x_C)^2 + (z - z_C)^2 = R^2, \quad (3)$$

where x_C, z_C are coordinates of point C. The position of point C can be written as $x_C = R_O \cos\alpha$, $z_C = R_O \sin\alpha$, then equation (3) will be as follows

$$(x - R_O \cos\alpha)^2 + (z - R_O \sin\alpha)^2 = R^2. \quad (4)$$

where R_O is the distance between points O and C; α is the angle of the pad relative to the centre of the wheel of the car.

The position of point A' is determined using the equation system

$$\begin{cases} x^2 + z^2 = OA^2, \\ (x - R_O \cos\alpha)^2 + (z - R_O \sin\alpha)^2 = R^2, \end{cases} \quad (5)$$

it should be noted that the coordinates of point A' $x_{A'}$, $z_{A'} > 0$, in the selected coordinate system.

To determine the coordinates of points A, K, K', N' the diagram of rotation of the shoe with the pad is considered in details.

The diagram of rotation of the shoe with the pad relative to the pendulum suspension is shown in Fig. 4.

Position of points A, K are related to the initial parameters of the "pendulum suspension – shoe – brake pad" system, initial pad thickness, wear value l, shoe size, wear of the pendulum suspension in the contact area with the shoe and the side frame of the bogie. To solve the problem, it was assumed that the shoe and brake shoe have standard sizes.

Angle β is defined as the angle between two vectors OA and OA', which is the angle of rotation of the pad relative to point O

$$\beta = \arccos\left(\frac{x_A \cdot x_{A'} + z_A \cdot z_{A'}}{\sqrt{\left(x_A^2 + z_A^2\right)}\sqrt{\left(x_{A'}^2 + z_{A'}^2\right)}}\right). \quad (6)$$

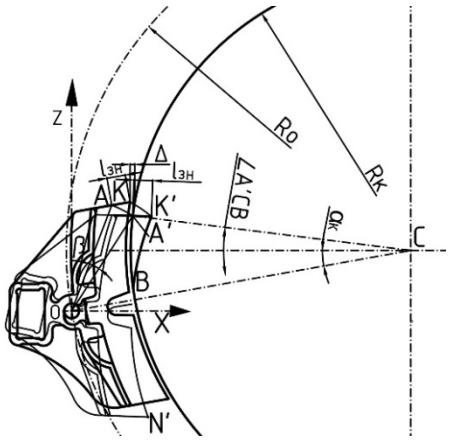

Fig. 4. Theoretical diagram of rotation of the shoe with the pad relative to the pendulum suspension.

Coordinates of points K', N' are determined from the known angle β and initial points K, N.

To find the position of point D, circles with radius $R+\Delta$ are drawn from points K', N' (where Δ is the clearance between the pad and the wheel in the free state without turning the shoe with the pad) and their point of intersection is found which is point D

$$\begin{cases}\left(x - x_{K'}\right)^2 + \left(z - z_{K'}\right)^2 = \left(R + \Delta\right)^2, \\ \left(x - x_{N'}\right)^2 + \left(z - z_{N'}\right)^2 = \left(R + \Delta\right)^2. \end{cases} \quad (7)$$

Coordinates of point B can be found as the intersection point of the circle with the centre at point C circle radius R and in point D with the radius $R+\Delta$. An equation system is composed to determine those

$$\begin{cases}\left(x - R_O\cos\alpha\right)^2 + \left(z - R_O\sin\alpha\right)^2 = R^2, \\ \left(x - x_D\right)^2 + \left(z - z_D\right)^2 = \left(R + \Delta\right)^2. \end{cases} \quad (8)$$

Once the coordinates of points A' and B are found, angle $\angle A'CB$ can be found as an angle between two right lines CA' and CB.

Let us denote

$$U = \left(z_C - z_{A'}\right)\left(z_C - z_B\right) + \left(x_{A'} - x_C\right)\left(x_B - x_C\right),$$

$$V = \left(z_C - z_{A'}\right)^2 + \left(x_{A'} - x_C\right)^2,$$

$$L = \left(z_C - z_B\right)^2 + \left(x_B - x_C\right)^2,$$

$$\cos\angle A'CB = \frac{|V|}{\sqrt{U \cdot L}}, \quad (9)$$

hence

$$\angle A'CB = \arccos\left(\frac{|V|}{\sqrt{U \cdot L}}\right). \quad (10)$$

Knowing the angle $\angle A'CB$, the length of the arc is determined using the formula (1).

All the above equations were solved using Mathcad software [14]. Capabilities of the graphics software complex AutoCAD were used to compare the results of the calculation of the obtained data. The results of the calculation in AutoCAD of the dependence of the lengths of harmful wear of the brake pad on its known horizontal wear at the top and the clearances between the pad and the wheel are summarized in Table 1, while an example of graphical determination is shown in Fig. 5.

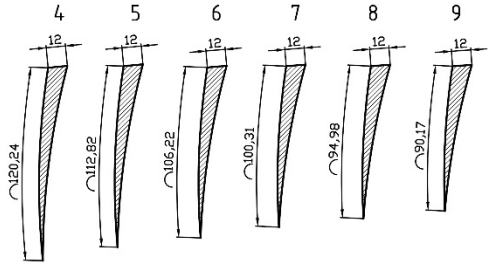

Fig. 5. Design diagrams of geometrical parameters of composite brake pad in AutoCAD with the upper wear of 12 mm and different clearances between the pad and the wheel from 4 to 9 mm

Table 1. Dependence of the wear length of the composite block on its horizontal wear and the clearance between the wheel and the pad

Clearance Δ, mm	Known value of horizontal wear of the brake pad, *l*, mm													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Defined length of a harmful wear of the brake pad, mm													
4	33.02	54.68	70.02	81.45	90.28	97.3	102.98	107.68	111.61	114.95	117.79	120.24	122.37	124.24
5	27.24	46.53	60.92	72.05	80.9	88.21	94.05	99.05	103.29	106.94	110.08	112.82	115.23	117.35
6	23.16	40.45	53.86	64.53	73.23	80.49	86.49	91.64	96.07	99.92	103.27	106.22	108.83	111.15
7	20.12	35.75	48.22	58.39	66.84	73.99	80.00	85.22	89.75	93.73	97.21	100.31	103.06	105.53
8	17.78	32.00	43.62	53.29	61.43	68.43	74.39	79.60	84.17	88.22	91.79	94.98	97.85	100.43
9	15.91	28.95	39.81	48.98	56.81	63.59	69.47	74.65	79.22	83.29	86.91	90.17	93.11	95.76

Comparison of the data obtained in AutoCAD and Mathcad for 4 to 9 mm clearances between the pad and the wheel in numerical (Fig. 6, a) and percentage (Fig. 6, b) values, with the 12 mm abrasion of the top.

4.2 Determination of the area of uneven pad wear

Let us consider the calculation diagram for determining the wear area of the brake pad of a freight car (Fig. 7).

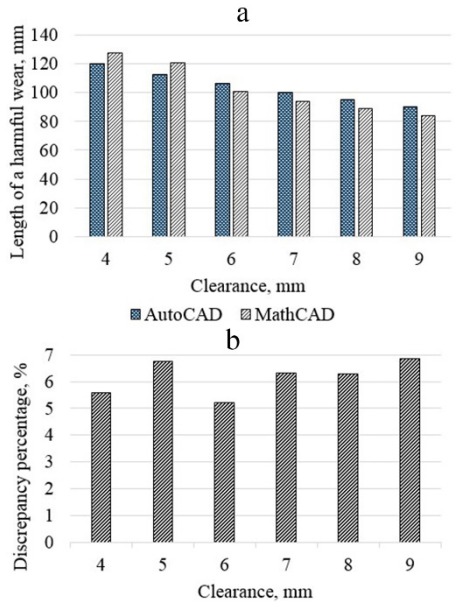

Fig. 6. Discrepancy between the results of AutoCAD and Mathcad: a – numerical values; b – percentage values.

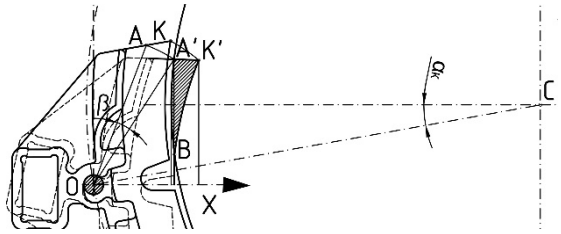

Fig. 7. Diagram for determining the area of uneven wear of the brake pad.

The area of the uneven wear of the brake pad can be defined as the area of the curvilinear trapezoid $Q = \int_a^b f(x)dx$, which requires composing an equation of the right line which goes through points A', K'

$$\frac{x-x_{A'}}{x_{K'}-x_{A'}} = \frac{z-z_{A'}}{z_{K'}-z_{A'}}, \text{ or } z = \frac{(x-x_{A'})(z_{K'}-z_{A'})}{x_{K'}-x_{A'}} + z_{A'}.$$

The circle that simulates a car wheel

$$(z-z_C)^2 + (x-x_C)^2 = R^2, \quad z = \sqrt{R^2-(x-x_C)^2} + z_C.$$

The circle that goes through points B, K' with the centre in point D (Fig. 3)

$$(z-z_D)^2 + (x-x_D)^2 = (R+\Delta)^2,$$

$$z = \sqrt{(R+\Delta)^2-(x-x_D)^2} + z_D.$$

Area of the uneven wear

$$Q = \int_{x_{A'}}^{x_{K'}} \left(\frac{(x-x_{A'})(z_{K'}-z_{A'})}{x_{K'}-x_{A'}} + z_{A'}\right) dx -$$
$$- \int_{x_B}^{x_{K'}} \left(\sqrt{(R+\Delta)^2-(x-x_D)^2} + z_D\right) dx -$$
$$- \int_{x_{A'}}^{x_B} \left(\sqrt{R^2-(x-x_C)^2} + z_C\right) dx +$$
$$+ \int_{x_C-R}^{x_{A'}} \left(\sqrt{R^2-(x-x_C)^2} + z_C\right) dx.$$

According to the results of the conducted studies, the graphical dependences of the harmful volume (V) of the pad wear (Fig. 8) on the magnitudes of the clearance between the pad and the wheel in case of the known horizontal wear at the top of the pad and the clearance between the pad and the wheel are shown.

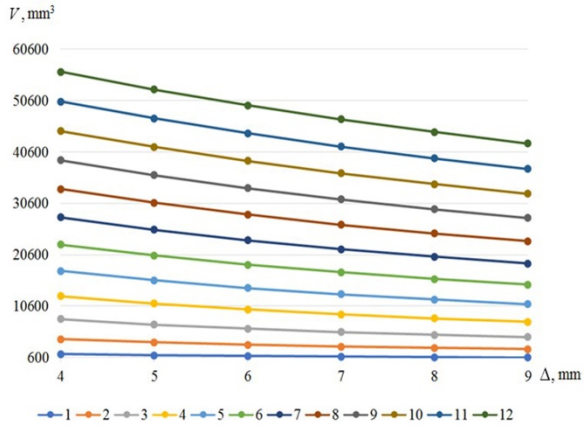

Fig. 8. Dependence of the amount of harmful wear in case of the known horizontal wear of the top of the pad and the clearance between the wheel and the pad.

To solve the problem of eliminating abnormal wear of the brake pads of freight cars, a device was proposed (Fig. 9) [15]. In the design, the brake strut was changed to prevent the abnormal wear of the brake pads in the bogies of freight cars for the entire regulated service life.

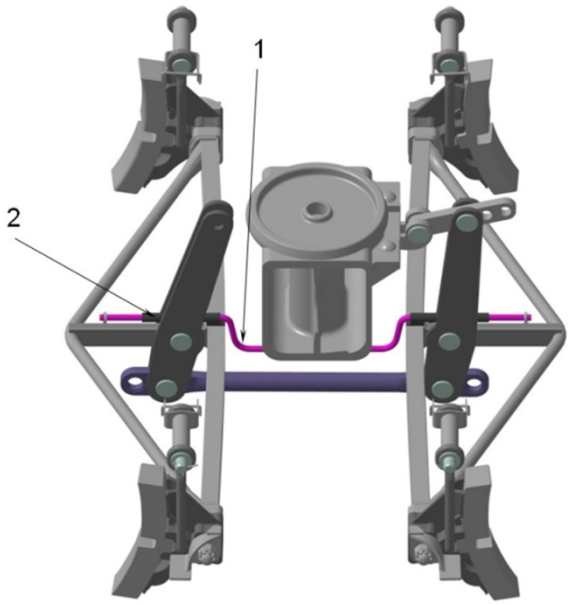

Fig. 9. General view of the device for standard retraction of the pads from the wheels in the brake system of freight cars:
1 – curved guide bar; 2 – cylindrical sliders

This result is achieved when the triangle is balanced in the suspension axes and fixed when the brake is released and the pads are uniformly retracted without partial touching the wheels. The proposed device has two pairs of brake pads, which are rigidly fixed in the brake shoes on the centre shafts of triangles and are held near the rolling surface of the wheels on the pendulum suspension of the bogie; two-arm vertical levers that are hinged to the brake strut in which the joining hinge is located on the same straight line along the triangle pendulum suspension axis.

It consists of a curved guide bar, the ends of which are hinged in cylindrical sliders, rigidly attached along the adjacent brake struts symmetrically relative to the opening of the hinge that joins two-arm levers, while the downward cranked portions of the bar prevent the truck bolster of the car from resting on it in the loaded state and also prevent shifting and falling.

Introduction of distinctive features not only eliminates the negative effect of forces acting on the triangle when the brake is retracted from the mass of vertical levers, due to the location of the centre of the hinge that joins the vertical levers to the brake strut on the same line with the centres of the two support hinges of the brake shoes, at the same time, the curved guide bar will provide straightforward retraction of the brake pads from the wheels and hold them firmly parallel to the wheels when the brake is released, which generally simplifies the design of the device and provides more reliable operation in terms of uniform wear of brake pads.

5 Conclusions

On the basis of the conducted studies, the following conclusions can be drawn:

1. It is established that the wedge dual wear of the brake pads occurs due to the malfunction of the device for uniform retraction and retention of the brake pads relative to the moving surface of the counter body, which requires braking.

2. It is proved that the smaller the clearance between the pad and the wheel, and accordingly, the angle between the surface of the wheel rim and the working part of the pad is, the greater length of the brake pad from the top is worn when the brakes are released. However, it should be noted that with an excessive clearance, which is generally larger at the bottom of the pad than at top, intense wear at the upper edge of the pad occurs.

3. The principles of methodology for determining the geometrical parameters of brake pads of freight car are developed when the upper harmful attrition occurs, depending on the clearance between the pad and the wheel. Graphical dependences of the geometrical parameters of the pads were obtained according to the developed methodology, which in further works will allow estimating the braking efficiency of the freight train.

4. The results of calculations of the coordinate method performed in the Mathcad software environment and of the graphical one performed in AutoCAD to determine the geometrical parameters of the formation of the upper harmful wear of the pad depending on the standard clearance between the wheel and the brake pad were compared to proved theoretically that the error between them does not exceed 5-7%.

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Determination of forces in the elements of the brake rigging of bogies of freight cars

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Abstract. The article presents the results of studies the purpose of which was solving the problem of deceleration of abnormal wear of brake pads in freight cars of Ukrzaliznytsia JSC. In the studies, the design schemes of brake rigging during braking were considered theoretically. Particular attention was paid to the determination of force loads acting in the rods of the rigging and the contact area of the brake pads with the rolling surfaces of the wheels during braking. Design analysis was performed to determine rational solutions from the point of view of determined force load of the rigging elements of the bogies during braking, in particular, taking into account the action of harmful torque caused by the movement of the bogie on inequalities "track joints". Based on the conducted studies, it was decided to create a 2D generalized model diagram to determine reliable information on the operation of triangle brake rigging.

1 Introduction

Today, the main task of Ukrzaliznytsya JSC is increasing the volume of freight transportation, which requires increasing the weight and the speed of freight trains. This can only be achieved provided the brakes are failure-proof and that timely maintenance and repair of freight cars is performed. However, the maintenance conditions of the brake equipment of freight cars have deteriorated significantly in recent years. This is a major factor hampering the increase in the volume of freight transportations by the Ukrainian railways.

According to the inspection of the braking systems in the three-element bogies under operating conditions, it was found that the multiple pads in operation have excessive tilt when the brakes are released. Their upper ends rest against the rolling surface of the wheels which causes friction during the movement of the car (Fig. 1, a). Thus, two wear planes are formed on the working surface of the pad: the upper one, on which the pad wears obliquely symmetrically (Fig. 1, b); and the lower one which is used for braking.

In turn, it should be noted that such wedge dual pads lead to the occurrence of thermomechanical damage to the rolling surface of the wheels during braking (Fig. 1, c) which compromises the traffic safety and increases the repair costs.

In view of the above, in Ukrzaliznytsia JSC and in the leading universities related to railway transport the work is being done to improve the reliability of the brake systems of freight trains.

Until now, 2D model diagrams of operation of brake rigging (BR) of various designs have been commonly considered in practice; they were used by the authors as a basis to propose a generalized mathematical design model for which theoretical studies with corresponding calculations have been performed.

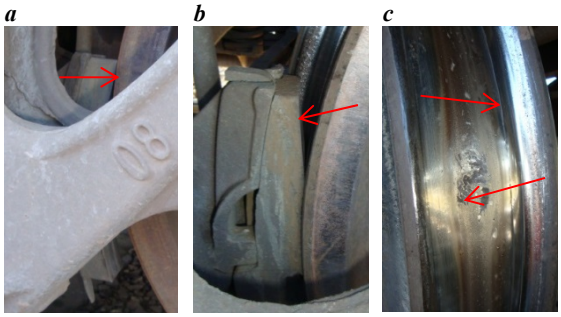

Fig. 1. Defect on wheels caused by abnormally worn brake pads: a – interaction of the upper end with the rolling surface of the wheel during movement of the car; b – braking with the wedge-worn pad; c – thermomechanical defects on the rolling surface of the wheel due to the increased braking time.

2 Analysis of recent research and publications

The study of scientific, technical and promotional sources of information on the operability of BR of modern freight cars proves that none of the developed rigging designs of bogies [1, 2, 3] can solve the problem because the developers proposed to create various auxiliary devices for counteracting forces which make the pads tilt until they touch the wheels in the bogies only on the basis of kinetostatic analysis of the BR mechanism [4].

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In [5] it was determined that the BR configuration currently used in two-axle freight cars, even with the brake pads of maximum thickness, cannot ensure their wear to the minimum permissible value in operation without additional manual adjustment. However, the authors of the article do not cover the issue of the wedge dual wear of the brake pads. In [6], a method of estimation of brake pad presses was developed, which includes structural analysis of the BR mechanism, determination of position of elements based on the coordinate method, and force analysis in which the BR is considered as a static flat mechanism. Studies were conducted at nominal brake pad sizes and different wheel diameters, but issues related to wedge dual friction wear and its effect on the braking force were not considered. In [7] the coordination of the dimension chains of BR of a freight car is substantiated in order to determine the nature and magnitude of wear of the brake pads of freight cars. A method for calculating the size chains of BRs is proposed, which allows determining the limit deviations of the component elements for the brake pads, which wear evenly.

In [8], the dynamic forces effecting the load-bearing structure of freight car bodies and related to the safe movement during operation in international traffic were analyzed, but the issue of change of the three-element bogie braking system was not considered.

In [9] the stresses occurring in the brake pad were analyzed, the thermal analysis using SolidWorks software was performed and an alternative solution for improving the brake pad material and increasing their life was suggested.

The authors in [10] refer to various friction brake systems used in mechanical braking. It is noted that friction brake systems in which brake pads are used have adverse effect on the rolling surface of the wheels, as high temperatures occur in the "pad-wheel" friction zone, so disc brakes are preferred

Using conventional methods of research, a dimensional analogue model with finite elements of the brake block on wheels was developed in [11], which was combined through a contact interface to control of the heat produced during braking, as well as heat distribution on the surface of the wheel block through thermal contact supports. The effect of temperature in wheels and brake blocks during braking was analyzed in experimental studies on a brake test bench in [12, 13].

The analysis of the literature suggests that the problems of operation of the brake systems of the three-element bogies in which the wedge dual wear of brake pads occurs have not been given sufficient attention.

3 Purpose and tasks of the study

The purpose of this study is creating a 2D generalized brake rigging model which will be used to find a rational solution to neutralize the effect of harmful torque in the triangle brake systems of bogies of freight cars.

To achieve the stated purpose, the following tasks must be solved:

- considering 2D design model diagrams during braking of three-element bogies of freight cars for different design solutions of the brake rigging;
- developing a generalized model of modern brake rigging of freight cars which will allow interpreting its operation in the form of non-inertial and inertial 2D kinematic schemes;
- performing calculations of the force factors effecting the rigging elements during braking of the bogie for various cases, to be used as the basis for finding a rational solution for reducing the harmful effect of torque, as well as to take into account the operational conditions of the freight car when the bogies roll over the inequality "rail joint";
- proposing actions to neutralize the effect of harmful torque which upsets a balance of the triangle of the brake rigging of the three-element bogie of the freight car.

4 Results and discussion

To reduce the possible effect of the harmful torque caused by the dynamics of the movement of freight cars, let us consider the BR triangles of three-element bogies and analyze ways to improve them. Fig. 2 shows a model bogie BR of a freight car. Investigating the structure of this mechanism makes it clear that it has redundant connections, so determining kinematics and performing its dynamic analysis immediately; finding inertial force factors affecting the BR from its parts is also impossible. As a result, kinetostatic analysis of this complex mechanism requires either imposing certain constraints, or considering its dynamics using a second-order Lagrange equation.

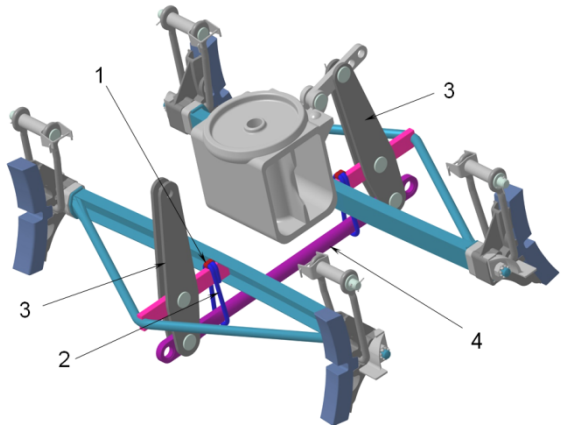

Fig. 2. General view of the BR model of the four-axle bogie of the freight car: 1 – locking device; 2 – bracer for even wear of pads; 3 – vertical lever; 4 – bridle.

If the first option is chosen, it is advisable to consider, for design reasons, that in operation of "symmetrical" BR, the force presses of the brake pads on the wheels are numerically identical. Then the spatial designs of freight car bogies with BR can be reduced to 2D braking diagrams, and in the future this will be considered for only one wheel pair.

Let us conditionally divide the BR of the bogie into two parts, which are attributed to the first (right) and the second (left) wheel pair (Fig. 3). The first part (the first wheel pair) has triangle No. 1, with a leading vertical

lever through which along with other BR parts braking force $T_0(t)$ is transferred from the pneumatic brake system and through lever 1 activates triangle No. 1, which with its brake shoes with pads 4 presses the wheels of the first wheel pair and brakes it. At the same time, the effect of forces on the first lever, which balance reaction of T_1 from the pressure forces of the pads of triangle No. 1 on the wheels; force N_1 in the pendulum suspensions of triangle No. 1, as well as internal force δT, which cannot be found immediately by the conventional method of forces due to the excessive degree of freedom of BR [14].

The second part (the second wheel pair) has its triangle No. 2, the vertical (driven) lever 2, to which an undetermined internal force δT is transmitted through the spacer of both levers in the opposite direction.

To understand the principle of operation of the triangular BR, it is sufficient to focus on a static analysis of the actions of the above power factors, without taking into account weight of its parts. It is clear that the geometry ratio of the parameters of the symmetric BR can be chosen so that pressing of the brake pads on the wheels of each of the two wheel pairs in their contact areas were numerically identical, i.e. reaction $T_1 = T_2$.

In the diagram (Fig. 3), some external forces and moments are shown in the red arrows for better perception of the scheme, while internal reactions in the spacer of vertical levers are shown in yellow.

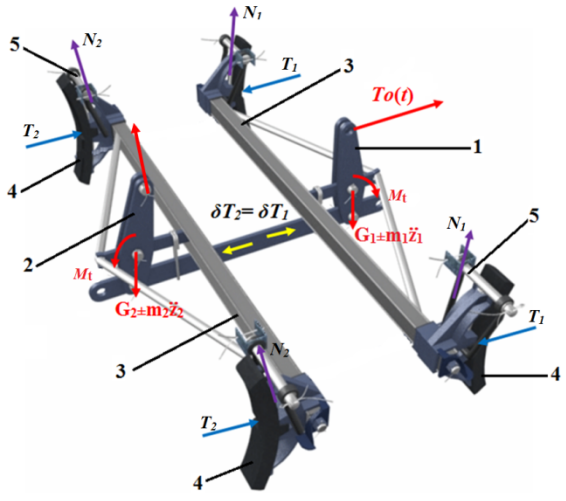

Fig. 3. General view of the BR model when force $T_0(t)$ is transmitted during braking of the freight car: 1, 2 – vertical lever; 3 – triangle; 4 – brake pad; 5 – pendulum suspension.

Classical mechanics problems which involve equilibrium equations of the chosen model (statics, kinematics with dynamics elements and dynamics in the form of Lagrange equations of the second kind) can be solved using different methods. It depends on the formulation of the problem, which in our case is reduced to a static bar system. However, these can be solved using either the force, or displacement, or hybrid method. The force method will be applied for further designing.

Earlier studies [4] analyzed in detail the problem associated with the design of BR bogies and the excessive wear of their brake pads. In this article, we investigated the case of reducing the weight of the BR triangular structure to zero (non-inertial system). The calculations established a decrease of the base pressure values of the pads on the rolling surface of the wheels, which corresponds to the expected decrease in the intensity of their wear (Fig. 4, a). However, this result can only be achieved theoretically. In addition, braking safety conditions are violated in this case, which is unacceptable.

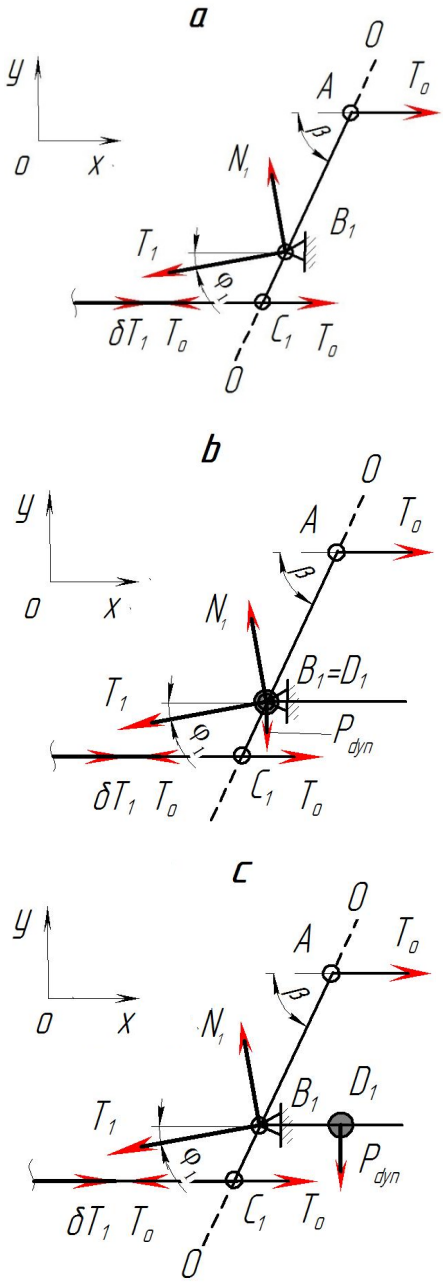

Fig. 4. Calculation model diagrams of the braked first (right) wheel pair when it rolls over the inequality „rail joint“ (phase 2).

The operation of BR was theoretically considered, where, ideally, its centre of mass and the connection knot of the triangle spacer with the leading lever (Fig. 4, b) are initially experimentally reduced to a single

straight line (suspension axis of the triangle). Although in this case the desired result regarding the calculations of force actions in all links of the triangular BR seems to be achieved, it is very difficult to achieve in practice.

In this sense, a real model diagram (Fig. 4, c) was considered separately without using auxiliary devices and without any significant changes in the typical triangle design.

Here, effect of harmful torque M_t was reduced and the problem of deceleration of the wear rate of the brake pad was partially solved. Upgraded BR triangles became more efficient than typical brakes of wheel pairs, mainly due to the action of the braking force $P_o(t)$, normally occurring during braking [15]. However, without an ingenious theoretical analysis of the operation of triangle BRs, the results of search for design solutions are discrepant as to the reduction of the harmful effects of M_t, there are only not substantiated (approximate) solutions. Indeed, for triangle No. 1, which is suspended to the bogie by two pendulum suspensions for brake shoes with first wheel pair pads, a rational solution in this regard is when the centre of mass C_1 (Fig. 4, c) is on axis *O*-*O*.

In the authors' opinion, the "perfect" BR design among the considered ones is the model (Fig. 4, a), where there is a non-inertial triangle, i.e., there are no dangerous stress factors.

The model (Fig. 4, b) can be considered to be close to the reality. Here, the combined center of gravity of the triangle is on its carrier beam. Then the influence of dangerous force factors is minimal (tending to zero). However, such a solution requires the installation of auxiliary balances behind the carrier beam on the other side of the triangle, which is next to impossible.

The other model is realistic and associated with the maximum possible displacement of the opening to connect the vertical lever to the brake strut as close as possible to its beam (Fig. 4, c and Fig. 5). This design solution was patented.

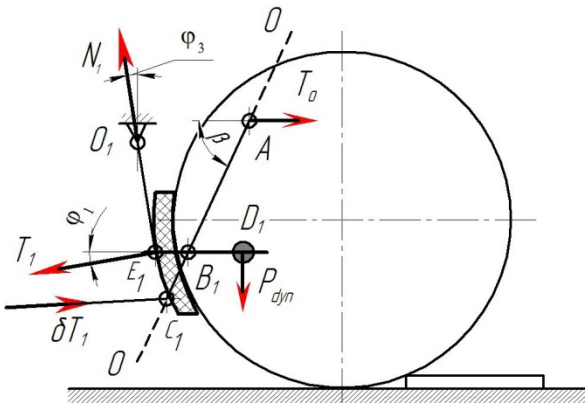

Fig. 5. Combined 2D model diagram for braking the right wheel pair rolling over the inequality "rail joint".

4.1 Theoretical calculation method of analysis of operation of BR

Concerning general movement and braking of a freight train, let us consider the phases of movement of a separate wheel pair of a bogie: no braking – phase 0; braking with movement – phase 1, or without any movement (full service braking) – phase 2.

Let us consider phase 0. In the released state of the brake system, the proposed design changes to the triangle include retaining the brake pads without tilting to the rolling surfaces of the wheels to prevent harmful upper wedge dual wear of the pads.

However, since the statically balanced triangle is held in such a "free" state in its suspension joints by friction forces only at the hinge joints, it cannot be ruled out that vibration of the undercarriage of the moving car on the track inequalities may from time to time make the triangle with the shoes and pads tilt in one direction or the other. In this case, the upper parts of the edges of pads in the released state due to the above vibration touch the rolling surface of the wheels.

It should be noted that, in general, the combined centre of mass of the triangle with its attached BR parts cannot be stationary at any particular point, at least because during the "free" movement, unlike braking, the centres of mass of each element of BR change their locations. Therefore, in the comparative analysis of the action of force factors on BR elements in various design schemes, it is appropriate to consider braking phase 3 with the intermediate location of the total centre of mass C_1 of the triangle with its parts [16].

From the point of view of kinetostatic analysis of BR operation, where the force factors act on the components of the brake system of the bogie in the classic situation of the bogie hitting isolated irregularity η or on other irregularities of the track, the kinematic diagrams of BR will have different forms and correspond to more than one phases of use of the rigging.

Approximate solutions to this problem for different 2D model diagrams can be obtained using the generalized scheme (Fig. 5), where it is shown that during the modernization of the triangle with the restoration of its spacer in the depot, a positive result was obtained, which was verified (Fig. 4, b).

Let us draw a generalized model diagram of operation of the triangle BR during braking (phase 2) from which all the above follow.

Let us consider phase 2. Supposing a BR bogie brakes in Phase 1 or Phase 2, and the combined centre of gravity of triangle No. 1 of the right wheel pair with the attached elements (probably point C_1) first crosses the space above the "rail joint" [14].

Then there is a formalized calculation scheme of the braked first (right) wheel pair when it roll over the inequality "rail joint" taking into account the effect of gravitational force (Fig. 5).

According to the condition of the use of a typical brake in a freight car, the effect of force factors on the BR is reproduced as follows. Under the action of external force $T_0(t)$, which changes together with the change in pressure in the brake pneumatic cylinder, an initial impulse to the first braking phase appears, where this force increases its value to T_0 and causes strain of forces N_1 in the suspension rods of triangle No. 1.

At the same time, force T_0 is divided to virtual force δT, which together with it will press the wheels of the

first and second wheel pairs through the pads. Virtual force δT in general can move the spacer connecting levers 1 and 2 (Fig. 3) either forward (right) or back (left) [14, 16].

In the end of the braking phase, when the pads of triangles No. 1 and No. 2 already rest against the wheels of the first and second wheel pairs, and the car is either slowing down or stops at all.

Let us consider the static equilibrium equation for BR (general case) and get separate solutions for the right part of the bogie with BR (Fig 5).

These mathematical models (1) and (2) are valid for the case of unilateral pressing of the pads on the wheels, the standard values of the angles of the pads were also taken into account (Table 1).

$$\sum X = 0;\ \ T_0 + \delta T - N_1 \sin\varphi_1 - T_1 cos\varphi_1 = 0; \qquad (1)$$

$$\sum Y = 0;\ \ N_1 \cos\varphi_1 - T_1 sin\varphi_1 - P_{dyn} = 0; \qquad (2)$$

$$\begin{aligned}\sum M_{B_1} = 0;\ \ & T_0 \cdot l_{B_1C_1} \cdot sin\beta - P_{dyn} l_{B_1D_1} - \\ & - N_1 \cdot l_{B_1E_1} \cdot cos\varphi_1 - T_1 \cdot l_{B_1E_1} \cdot sin\varphi_1 + \\ & + \delta T \cdot l_{B_1C_1} \cdot sin\beta - M_0 = 0,\end{aligned} \qquad (3)$$

where M_0 is compensating moment which occurs when the pad presses on the wheel and is $M_0 = T_0 \cdot l_{AC_1} \cdot sin\beta$; P_{dyn} is inertial force which occurs in the triangle when the wheel hits the obstacle and moves the triangle with the pads towards the wheel (on the basis of the previous studies, it is assumed P_{dyn} = 1 kN); $l_{B_1C_1}$, $l_{B_1D_1}$, are geometrical parameters of BR elements (Table 1).

Table 1. Input parameters for calculations

Designation	Value, mm	Value, m
$l_{B_1C_1}$	160	0.16
$l_{B_1D_1}$	150	0.15
$l_{B_1O_1}$	50	0.05
l_{C_1A}	560	0.56
φ_1	10^0	$\cos\varphi_1 = 0.984$, $sin\,\varphi_1 = 0.1736$
β	$64^0 43' = 64.72^0$	$\cos\beta = 0.427$, $sin\,\beta = 0.904$

Equations (1) – (3) are easy to transform in the system of equations of the general form (4):

$$\begin{cases} T_0 + \delta T - N_1 \sin\varphi_1 - T_1 cos\varphi_1 = 0 \\ N_1 \cos\varphi_1 - T_1 sin\varphi_1 - P_{dyn} = 0 \\ T_0 \cdot l_{B_1C_1} \cdot sin\beta - P_{dyn} l_{B_1D_1} - N_1 \cdot l_{B_1E_1} \cdot cos\varphi_1 - \\ \quad - T_1 \cdot l_{B_1O_1} \cdot sin\varphi_1 + \delta T \cdot l_{B_1C_1} \cdot sin\beta - M_0 = 0 \end{cases}. \qquad (4)$$

After vector of unknown forces $\Delta = (N_1, T_1, \delta T)$ is introduced, the matrix of the equation system will have the form G, in which the right side of the matrix has the form of the column vector R:

$$G = \begin{bmatrix} -sin\varphi_1 & -cos\varphi_1 & 1 \\ -\ cos\varphi_1 & -sin\varphi_1 & 0 \\ -l_{B_1E_1} \cdot cos\varphi_1 & -l_{B_1O_1} \cdot sin\varphi_1 & l_{B_1C_1} \cdot sin\beta \end{bmatrix}, \qquad (5)$$

$$R = \begin{bmatrix} -T_0 \\ P_{dyn} \\ -T_0 \cdot l_{B_1C_1} \cdot sin\beta + P_{dyn} \cdot l_{B_1D_1} + T_0 \cdot l_{AC_1} \cdot sin\beta \end{bmatrix}. \qquad (6)$$

To solve the system of equations by the Kramer method, the matrix determinant $G = \Delta$ should be found. Unless it is zero, the system of linear algebraic equations has a unique solution.

$$G = \begin{bmatrix} -0.1736 & -0.984 & 1 \\ -\ 0.984 & -0.1736 & 0 \\ -0.05 \cdot 0.984 & -0.05 \cdot 0.1736 & 0.16 \cdot 0.904 \end{bmatrix} =$$

$$= \begin{bmatrix} -0.1736 & -0.984 & 1 \\ -\ 0.984 & -0.1736 & 0 \\ -0492 & -0,00868 & 0.14464 \end{bmatrix}.$$

$$R = \begin{bmatrix} -13.4 \\ 1 \\ -13.4 \cdot 0.16 \cdot 0.904 + 1 \cdot 0.15 + 13.4 \cdot 0.56 \cdot 0.904 \end{bmatrix} =$$

$$= \begin{bmatrix} -13.4 \\ 1 \\ 4,99544 \end{bmatrix}.$$

Forces to be found will be calculated for each moment of time using the formulas:

$$N_1 = \frac{\Delta_1}{\Delta}, \quad T_1 = \frac{\Delta_2}{\Delta}, \quad \delta T = \frac{\Delta_3}{\Delta}, \qquad (6)$$

where Δ_1, Δ_2, Δ_3 are determinants of matrices in which according to the index of column (1, 2, 3) of the matrix (5), the systems are replaced by a column of the matrix (6).

$$N_1 = \frac{1.3546814976}{0.14444075577344},$$

$$T_1 = \frac{6.84676864}{0.14444075577344},$$

$$\delta T = \frac{5.0373317761024}{0.14444075577344}.$$

Practice or experiment is known to be the criterion for the adequacy of any design model. In our case, the operational testing of the upgraded BR of freight cars has shown that improved performance ensures the specified wear of the brake pads and increases their service life.

4.2 Analysis of calculation schemes for designing BR

The plan of positions of BR during braking in phase 2 for the bogie of the 18-100 freight car is considered. All necessary initial data for obtaining solutions are given in Table 1. Force factors which exist in the components of bogie BR were found using the Mathcad software (Table 2).

Table 2. Comparison of identified forces acting in the BR elements

Calculated scheme	T_1, kN	T_2, kN	N_1, kN	N_2, kN
Typical	46.0	46.0	-	-
Scheme a)	45.53	45.53	8.03	8.03
Scheme b)	40.97	40.97	7.13	7.13
Scheme c)	47.4	47.4	9.8	9.8
United	47.413	47.413	9.381	9.381

The obtained calculations prove that the design changes of BR, which reflect the considered model diagrams, have significant differences with respect to the determined force loads of the elements of the triangular BRs.

It was also found that a shift of the technological opening of the triangle spacer can be considered the simplest rational solution, which can be used primarily in the "optimization' of the operating conditions of the braking system of the bogie, and accordingly, the train. This is achieved in a technologically accessible and economically feasible way in the facilities of the car repair enterprise and does not require significant capital investments.

The second step in the BR design improvement is definitely reduction of the total mass of the triangle with its elements and the dynamic balancing of its design which is associated with search for the "optimal" location of its centre of mass.

5 Conclusions

On the basis of the conducted studies, the following conclusions can be drawn:

1. 2D model diagrams were calculated for various design solutions of brake rigging, which enabled to identify the cause and solve the problem of deceleration of abnormal wear of the brake pads of freight cars.
2. According to the results of theoretical studies, a generalized model diagram of operation of triangle BRs was created and various schematic solutions were considered with their scientific substantiation.
3. Comparative design analysis was performed to determine rational solutions in terms of determined force load of elements of the brake rigging of the bogies during braking, taking into account the harmful torque.
4. The first step in terms of BR modernization was scientifically substantiated, which was achieved in a technologically accessible and economically feasible way at the facilities of the car repair enterprise and does not require any significant capital investments. On the basis of the results of the studies it was decided to create a 2D generalized model diagram to determine reliable information on the operation of triangular rigging transmissions of bogies of freight cars.

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The sustainable future of open-pit trucks operation

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Abstract. Open-pit truck technical operation determines mined bulk transportation effectiveness increasing equipment's commercial operation duration based on a robust strategy of vehicle's maintenance, early and high-quality diagnostics, upkeep and recovery. Developed mathematical model of BelAZ open-pit truck operation for various levels of organization of servicing replicates a Markov process in the system of technological automotive transport considering possibilities of vehicle states with time and steady-state condition. The performance of open-pit trucks was consistently evaluated and the model of the technological automotive transport system was synthesized. The validation analysis of the obtained model showed its suitability for optimization of open-pit truck performance. The calculated optimal controlling actions on the open-pit truck allow developing an algorithm and technique for dynamic adjustment of parameters of maintenance, diagnostics and repair of BELAZ open-pit trucks that will become the basis for a sustainable future of industrial transport technical operation.

1 Introduction

A status of open-pit mining is growing; the percentage of technological automobile transport that is a part of the transport and handling equipment of an open pit is increasing. The modern deep open pit is an enormous power-intensive enterprise that includes large truck fleet aimed to appropriate mined bulk transportation. Processing of large mineral resources volumes from open-pit mining causes the side effects related especially to its transportation [1-3]. Due to the deep depth (more than 300 meters) and the possibility of further advance at the lowest level of open pits in Ukraine as well as in the world, bulk transportation becomes increasingly difficult. From this, it follows that the problem of developing reliable and cost-effective systems for mined bulk transportation is especially acute.

Of more than two thousand BELAZ open-pit trucks works at Ukrainian enterprises representing above 90 % from the overall number of open-pit trucks of all manufactures introduced to our market. The largest business entities for BELAZ equipment operation are iron ore mining and processing enterprises of the city of Kryvyi Rih where about two-thirds of the overall number of Ukrainian open pit truck's fleet are accumulated including above 200 vehicles with electromechanical transmission and payload capacity of 120-220 tones that arrange for base quantity of mined bulk transportation. In 2018 the enterprises of Kryvyi Rih iron ore basin purchased 52 vehicles of BELAZ whereof 31 pit truck BELAZ-75131 with payload capacity of 130 tones [4].

The feature of the system of technological automotive transport (STAT) is the fact that it consists of an open-pit truck fleet and operates compatibly certain cycles, which are determined following a haulage roads design. The analytical review of the basic works, which are focused on technological automotive transport maintenance system evolution, has allowed establishing the too low level of its organization concerning open-pit trucks especially with the huge payload capacity [5-7].

Despite a considerable body of theoretical work existed in the technical literature [8], integrated mathematical models are currently absent that can be used to describe vehicle operations taking into consideration all engineering and resources conditions of equipment, state transition, loss of function, field maintenance and at the same time an industrial transport service costs minimization.

Multipronged implementation, system approach to open-pit truck maintenance improvement is evident as synchronous evolution of diagnostic and monitoring systems within the framework of an actual state service development considering all the advantages of scheduled preventive maintenance.

The reliability of the system of open pit's technological automotive transport is the main indicator for the cost-effective management of the pit trucks operation as well as for the production as a whole.

Long-term and reliable operation of open-pit trucks becomes possible provided timely, systematic and high-quality maintenance and repair; therefore, validation of operating parameters of technological vehicles in deep open pits is a crucial task.

2 Formulation of the problem

The goal of the research is an enhancement of operating efficiency of technological automotive transport of deep open pits via a solid approach to its maintenance

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parameters. The problem of a maintenance system improvement is qualified as the planning and design of vehicle's maintenance management technique, minimization of unit transportation costs. The study subject is a deep open pit technological automotive transport technical maintenance. The research also focuses on synergies between maintenance parameters and technical and economic features of deep open pit technological automotive transport.

3 Materials and methods

The technological states of open-pit trucks change over time randomly and unexpectedly. Importantly it would be safe to assume that there is the relationship of the BELAZ open-pit truck technological state in the future on its current state and regardless of how and when that state was reached at this point. With the view to the mathematical treatment of such technological states of the open-pit truck, it is considered appropriate to use a mathematical apparatus known as "Markov random processes". Besides, having regard to the three technological state subsystems of the open-pit truck are considered, mathematical modelling using the "Markov process with discrete states and continuous-time" pattern can be applied.

Figure 1 shows a marked graph of the subsystems of technological states of BELAZ open-pit truck during mining positing that the probability of being each of them is described by the Kolmogorov differential equation set:

$$\begin{cases} \frac{dP_0}{dt} = -(\lambda + \omega_1)P_0 + \mu_1 P_1 + \mu_2 P_2; \\ \frac{dP_1}{dt} = \lambda P_0 - (\mu_1 + \omega_2)P_1; \\ \frac{dP_2}{dt} = \omega_1 P_0 + \omega_2 P_1 - \mu_2 P_2, \end{cases} \quad (1)$$

where $P_0=P_0(t)$ – is the possibility of machine operation, $P_1=P_1(t)$ – is the possibility of scheduled maintenance, $P_2=P_2(t)$ – is the possibility of unscheduled operating repair.

At the initial time, it is expected that the open-pit truck is in working order:

$$P_0(t=0) = 1;\ P_1(t=0) = 0;\ \ P_2(t=0) = 0. \quad (2)$$

While the requirement of completeness of the STAT must also be fulfilled:

$$P_0(t) + P_1(t) + P_2(t) = 1 \quad (3)$$

Equations (1) and initial conditions (2) determine the Cauchy problem. In the furtherance of this goal, it is required to ensure the general solution of the differential equation system (1) and then, according to the initial conditions (2), determine the partial solution.

The solution of system (1) can be presented as follows:

$$P_i(t) = X_i \cdot e^{\theta_i \cdot t};\ (i = 0, 1, 2) \quad (4)$$

Substituting equation (4) into the system of differential equations (1), a homogeneous system of linear equations is depicted:

$$\begin{cases} -(\lambda + \omega_1 + \theta)X_0 + \mu_1 X_1 + \mu_2 X_2 = 0; \\ \lambda X_0 - (\mu_1 + \omega_2 + \theta)X_1 = 0; \\ \omega_1 X_0 + \omega_2 X_1 - (\mu_2 + \theta)X_2 = 0. \end{cases} \quad (5)$$

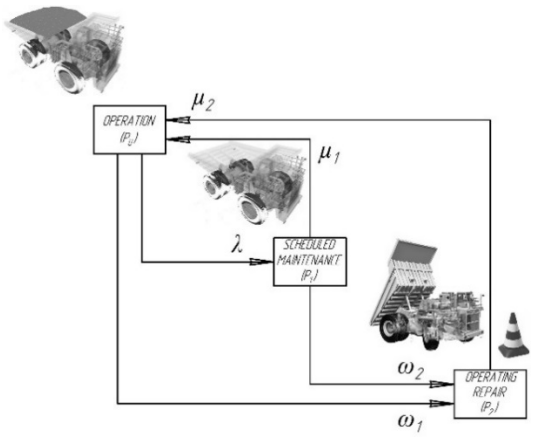


Fig. 1. The marked graphic chart of technological states of BelAZ open-pit truck: λ – is the open-pit truck transition rate from functional condition to state of scheduled maintenance and repairs; ω_1 – is the open-pit truck transition rate from functional condition to state of unscheduled operating repairs; ω_2 – is the open-pit truck transition rate from state of maintenance and repair to operating repair; μ_1, μ_2 – are the transition rates of open-pit trucks restoration to functional condition from states of maintenance and operating repair respectively.

For a homogeneous system of linear equations (5) its determinant must be zero to have a non-trivial solution:

$$\begin{vmatrix} -(\lambda + \omega_1 + \theta) & \mu_1 & \mu_2 \\ \lambda & -(\mu_1 + \omega_2 + \theta) & 0 \\ \omega_1 & \omega_2 & -(\mu_2 + \theta) \end{vmatrix} = 0. \quad (6)$$

Removing determinant (6), an equation for eigenvalues estimation is specified:

$$\theta^3 + \theta^2(\lambda + \omega_1 + \omega_2 + \mu_1 + \mu_2) + \\ +\theta(\lambda\mu_2 + \omega_2\mu_2 + \mu_1\mu_2 + \lambda\omega_2 + \omega_1\mu_1 + \omega_1\omega_2) = 0. \quad (7)$$

The solution of this equation is as follows

$$\theta_1 = 0;$$

$$\theta_2 = \frac{-(\lambda+\omega_1+\omega_2+\mu_1+\mu_2)-\sqrt{D}}{2}; \quad (8)$$

$$\theta_3 = \frac{-(\lambda+\omega_1+\omega_2+\mu_1+\mu_2)+\sqrt{D}}{2},$$

where $D = (\lambda + \omega_1 + \omega_2 + \mu_1 + \mu_2)^2 - 4(\lambda\mu_1 + \\ +\omega_2\mu_2 + \mu_1\mu_2 + \lambda\omega_2 + \omega_1\mu_1 + \omega_1\omega_2)$.

Conversely eigenvectors are estimated corresponding to the determined eigenvalues (8) by substituting these values into a system of linear equations (5).

The system of two equations is obtained for the values $\theta=\theta_i$:

$$\begin{cases} -(\lambda + \omega_1 + \theta_i)X_0 + \mu_1 X_1 + \mu_2 X_2 = 0; \\ \lambda X_0 - (\mu_1 + \omega_1 + \theta_i)X_1 = 0; \end{cases} .(i=1,2,3) \quad (9)$$

Considering X_0=1, by solving equation (9) the coordinates of the eigenvector corresponding to the eigenvalue are found:

$$x_1^{(i)} = 1;$$

$$x_2^{(i)} = \frac{\lambda}{\mu_1+\omega_1+\theta_i};\ (i=1,2,3) \qquad (10)$$

$$x_3^{(i)} = \frac{\theta_i^2+\theta_i(\lambda+\mu_1+2\omega_1)+\omega_1(\lambda+\mu_1+\omega_1)}{\mu_2(\mu_1+\omega_1+\theta_i)}.$$

Taking into account equation (10), a complementary solution of differential equation system (1) is written:

$$P_0(t) = C_1 + C_2e^{\theta_2 t} + C_3e^{\theta_3 t};$$

$$P_1(t) = \frac{\lambda}{\mu_1+\omega_1}C_1 + \frac{\lambda}{\mu_1+\omega_1+\theta_2}C_2e^{\theta_2 t} + \\ + \frac{\lambda}{\mu_1+\omega_1+\theta_3}C_3e^{\theta_3 t}; \qquad (11)$$

$$P_2(t) = \frac{\omega_1(\lambda+\mu_1+\omega_1)}{\mu_2(\mu_1+\omega_1)}C_1 + \\ + \frac{\theta_2^2+\theta_2(\lambda+\mu_1+2\omega_1)+\omega_1(\lambda+\mu_1+\omega_1)}{\mu_2(\mu_1+\omega_1+\theta_2)}C_2e^{\theta_2 t} + \\ + \frac{\theta_3^2+\theta_3(\lambda+\mu_1+2\omega_1)+\omega_1(\lambda+\mu_1+\omega_1)}{\mu_2(\mu_1+\omega_1+\theta_3)}C_3e^{\theta_3 t},$$

where C_1, C_2, C_3 – are the arbitrary constants.

To find arbitrary constants, initial condition is used (2), which gives a system of linear equations:

$$\begin{cases} C_1 + C_2 + C_3 = 1; \\ \frac{1}{\mu_1+\omega_1}C_1 + \frac{1}{\mu_1+\omega_1+\theta_2}C_2 + \frac{1}{\mu_1+\omega_1+\theta_3}C_3 = 0; \\ \frac{\omega_1(\lambda+\mu_1+\omega_1)}{\mu_2(\mu_1+\omega_1)}C_1 + \frac{\theta_2^2+\theta_2(\lambda+\mu_1+2\omega_1)+\omega_1(\lambda+\mu_1+\omega_1)}{\mu_2(\mu_1+\omega_1+\theta_2)}C_2 + \\ + \frac{\theta_3^2+\theta_3(\lambda+\mu_1+2\omega_1)+\omega_1(\lambda+\mu_1+\omega_1)}{\mu_2(\mu_1+\omega_1+\theta_3)}C_3 = 0. \end{cases} \qquad (12)$$

Solving system (12), we find

$$\begin{cases} C_1 = \frac{(\omega_2+\mu_1)\mu_2}{\lambda\mu_2+\omega_2\mu_2+\mu_1\mu_2+\lambda\omega_2+\omega_1\mu_1+\omega_1\omega_2}; \\ C_2 = \frac{(\omega_1+\mu_1+\theta_2)(\lambda+2\omega_1+\mu_1+\theta_3)}{\theta_2(\theta_2-\theta_3)}; \\ C_3 = \frac{(\omega_1+\mu_1+\theta_3)(\lambda+2\omega_1+\mu_1+\theta_2)}{\theta_3(\theta_3-\theta_2)}. \end{cases} \qquad (13)$$

Substituting equation (13) into complementary solution (11), handling the Cauchy problem is as follows:

$$P_0(t) = \frac{(\omega_2+\mu_1)\mu_2}{\lambda\mu_2+\omega_2\mu_2+\mu_1\mu_2+\lambda\omega_2+\omega_1\mu_1+\omega_1\omega_2} + \\ + \frac{(\omega_1+\mu_1+\theta_2)(\lambda+2\omega_1+\mu_1+\theta_3)}{\theta_2(\theta_2-\theta_3)}e^{\theta_2 t} + \\ + \frac{(\omega_1+\mu_1+\theta_3)(\lambda+2\omega_1+\mu_1+\theta_2)}{\theta_3(\theta_3-\theta_2)}e^{\theta_3 t};$$

$$P_1(t) = \frac{\lambda\mu_2}{\lambda\mu_2+\omega_2\mu_2+\mu_1\mu_2+\lambda\omega_2+\omega_1\mu_1+\omega_1\omega_2} + \\ + \frac{\lambda(\omega_1+\mu_1+\theta_2)(\lambda+2\omega_1+\mu_1+\theta_3)}{(\omega_1+\mu_1+\theta_2)\theta_2(\theta_2-\theta_3)}e^{\theta_2 t} + \\ + \frac{\lambda(\omega_1+\mu_1+\theta_3)(\lambda+2\omega_1+\mu_1+\theta_2)}{(\omega_1+\mu_1+\theta_3)\theta_3(\theta_3-\theta_2)}e^{\theta_3 t};$$

$$P_2(t) = \frac{\lambda\omega_2+\omega_1\omega_2+\omega_1\mu_1}{\lambda\mu_2+\omega_2\mu_2+\mu_1\mu_2+\lambda\omega_2+\omega_1\mu_1+\omega_1\omega_2} + \\ + \frac{\theta_2^2+\theta_2(\lambda+2\omega_1+\mu_1)+\omega_1(\lambda+\omega_1+\mu_1)(\lambda+2\omega_1+\mu_1+\theta_3)}{\mu_2\theta_2(\theta_2-\theta_3)}e^{\theta_2 t} + \\ + \frac{\theta_3^2+\theta_3(\lambda+2\omega_1+\mu_1)+\omega_1(\lambda+\omega_1+\mu_1)(\lambda+2\omega_1+\mu_1+\theta_2)}{\mu_2\theta_3(\theta_3-\theta_2)}e^{\theta_3 t}. \qquad (14)$$

The mathematical model, which is described by functions (14), allows us to determine the probabilities of BELAZ open-pit truck being in each of the subsystems of technological state.

However, the study of the operation of open-pit truck based on the derived mathematical model is some difficult which is due to the probabilities dependence on time.

Thus, it seems advisable to consider edge steady-state operating conditions wherein the system that describes the open-pit truck operation changes their states randomly but the probability each of them is no longer dependent on time. In this case, the probability characterizes the average relative residence time of open-pit truck in this state. To calculate these probabilities, it is sufficient to equate the derivatives to zeros in formulas (1), which gives three simultaneous linear equations in three variables:

$$\begin{cases} -(\lambda+\omega_1)P_0 + \mu_1P_1 + \mu_2P_2 = 0; \\ \lambda P_0 - (\mu_1+\omega_2)P_1 = 0; \\ \omega_1P_0 + \omega_2P_1 - \mu_2P_2 = 0. \end{cases} \qquad (15)$$

The resulting set of equations (15) is linearly dependent because its determinant is zero accordingly equation (6). Therefore, determining an appropriate solution is coming from the rejection of one equation and supplementing condition (2):

$$\begin{cases} -(\lambda+\omega_1)P_0 + \mu_1P_1 + \mu_2P_2 = 0; \\ \lambda P_0 - (\mu_1+\omega_2)P_1 = 0; \\ P_0 + P_1 + P_2 = 1. \end{cases} \qquad (16)$$

The linear system solving (16) is as follows

$$P_0 = \frac{(\omega_2+\mu_1)\mu_2}{(\lambda+\omega_2+\mu_1)\mu_2+(\lambda+\omega_1)\omega_2+\omega_1\mu_1}; \qquad (17)$$

$$P_1 = \frac{\lambda\mu_2}{(\lambda+\omega_2+\mu_1)\mu_2+(\lambda+\omega_1)\omega_2+\omega_1\mu_1}; \qquad (18)$$

$$P_2 = \frac{(\lambda+\omega_1)\omega_2+\omega_1\mu_1}{(\lambda+\omega_2+\mu_1)\mu_2+(\lambda+\omega_1)\omega_2+\omega_1\mu_1}. \qquad (19)$$

Formulas (17), (18), (19) determine the probabilities of open-pit being in stationary subsystems of technological states which are operation, scheduled maintenance and unscheduled operating repairs respectively.

The developed mathematical model of BELAZ open-pit truck operation (17-19) for the various management levels of maintenance, diagnostic and repair reproduces the Markov process occurring at the STAT and allows calculating machine state probability with time as well as without reference to time [4]. The open-pit trucks operation is consistently studied. Modelling machine states and transitions allowed calculating time-dependent system state probabilities, empowered to formulate the purpose and the function of the income from operating surplus described by the three basic states of open-pit trucks. By varying the parameters of the function, the

rational costs of the transportation system operation can be found [9].

As the part of developed mathematical model of transportation system of iron ore open pit that introduces technological states of the fleet of BELAZ open-pit trucks via calculation of statistically distributed numerical characteristics of these states, the management of the maintenance system is designed on the basis of economic criterion as an extremum problem subject to the constraints related to technological states of the system [10].

The analysis of the STAT of the deep open pit has allowed establishing that its control parameter, which characterizes and determines the intensity of scheduled preventive maintenance λ (Fig. 1), especially bears on its efficiency [11]. Therefore, it seems appropriate to investigate the relationship of this parameter with other parameters that characterize the operating of technological transport of mining and processing plants of the Kryvyi Rih iron ore basin. In this regard, it is necessary to confirm the ability to control the performance of the STAT by adjustment of the governing parameter based on the regulation of the control parameters. The substantiation of maintenance intervals is one of the main procedures of open-pit trucks reliability-assurance program and the quality policy of OJSC "BELAZ".

The technological automotive transport system took an assessment as exemplified by Central Iron Ore Enrichment Works (PJSC "Central GOK") where 5 new warranty and 44 non-warranty open-pit trucks BELAZ-75131 operated during 2015 (in 22 vehicles on mining workshops with number one and two).

Non-warranty BELAZ open-pit trucks are those for which one of three events have occurred since the beginning of operation namely a calendar time of 12 months or 6,000 running hours or 60,000 km.

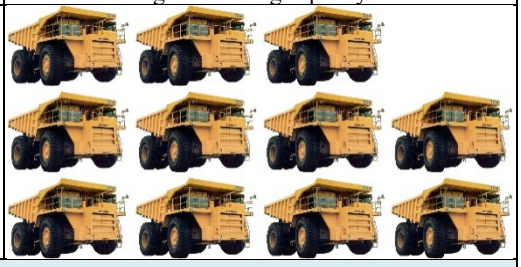
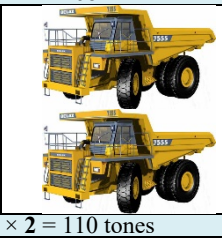
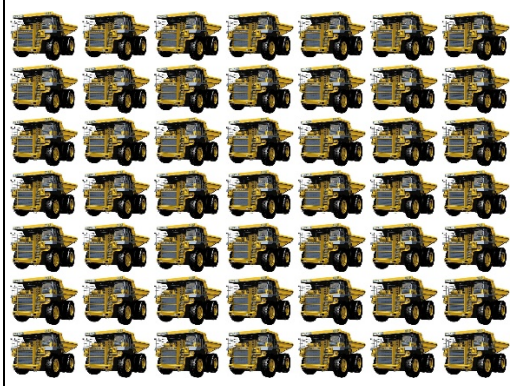
The above-mentioned vehicles truck about 700 m^3 of mined rock per shift and up to 1,500 m^3 per day. The analysis of the performance of BELAZ trucks at the open pit of PJSC "Central GOK" indicates the STAT parametric identification applicability which will allow, drawing from relevant statistical material, determining the values of the STAT mathematical model parameters as a consequence of structural identification.

The optimality criterion is the minimum of a man-hour expenditure of the maintenance

$$C = c_1 \cdot N_1 \cdot T_1 + c_2 \cdot N_2 \cdot T_2 \rightarrow \min_{\lambda,\, \omega_1,\, \omega_2,\, \mu_1,\, \mu_2} \quad (20)$$

where c_1 and c_2 – are the average expenditures of maintenance and unscheduled operating repairs, man-hour; N_k – is the number of trucks in k-th state, (k=1,2); T_k – is the time when the trucks are in k-th state, (k=1,2).

Table 1. BELAZ open-pit trucks fleet configuration at PJSC "Central GOK" in 2015.

Make of vehicle, model, loading capacity	The number of vehicles, gross loading capacity	Make of vehicle, model, loading capacity	The number of vehicles, gross loading capacity
			
BELAZ-7548	42 t × **4** = 168 tones		
		BELAZ-75145	120 t × **11** = 1320 tones
BELAZ-7555	55 t × **2** = 110 tones		
			
BELAZ-7519	110 t × **1** = 110 tones		
BELAZ-7512	120 t × **2** = 240 tones	BELAZ-75131	130 t × **49** = 6370 tones; Gross 8318 tones; Average 8318 / 69 ≈ 120 tones

The criterion allows realizing the optimal control problem from the perspective of the developed mathematical model, which reproduces the Markov process occurring at the STAT [11].

However, it has to be previously demonstrated that it is possible for the mathematical model of STAT operation implementation to be used in the form of a Markov process. In order to get that done consider an identification problem with the composite function [11], which is minimized by the same parameters as the optimality criterion of the STAT (20):

$$\sum_{i=1}^{N}((t_{0i} - T_i \cdot P_0)^2 + (t_{1i} - T_i \cdot P_1)^2 + (t_{0i} - T_i \cdot P_0) \cdot \cdot (t_{1i} - T_i \cdot P_1)) \to \min_{\lambda,\, \omega_1,\, \omega_2,\, \mu_1,\, \mu_2}, \quad (21)$$

where T_i – is the observation time over technological states of i-th truck, running hours; t_{0i}, t_{1i}, t_{2i} – is the total actual time of i-th truck being in each of above technological states throughout T_i, running hours; P_0=P_0(λ, ω_1, ω_2, μ_1, μ_2), P_1=P_1(λ, ω_1, ω_2, μ_1, μ_2), P_2=P_2(λ, ω_1, ω_2, μ_1, μ_2) – are probabilities of truck being in each of three technological states.

Finding the values of the parameters rather a solution to the problem of STAT parametric identification was carried out by minimizing the composite function discrepancy (21). For the convenience of further calculations, this function can be written

$$Q(P_0,\ P_1) = \sum_{i=1}^{N} T_i^2 \cdot \left(\left(\frac{t_{0i}}{T_i} - P_0\right)^2 + \left(\frac{t_{1i}}{T_i} - P_1\right)^2 + + \left(\frac{t_{0i}}{T_i} - P_0\right) \cdot \left(\frac{t_{1i}}{T_i} - P_1\right)\right) \to \min_{\lambda,\, \omega_1,\, \omega_2,\, \mu_1,\, \mu_2} \quad (22)$$

and apply the corresponding probabilities P_0, P_1 as the parameters where P_1=P_1(λ, ω_1, ω_2, μ_1, μ_2), P_0=P_0(λ, ω_1, ω_2, μ_1, μ_2).

By minimizing the function (22), the optimal values were founded from certain parameters in response to parametric identification of the STAT

Given the rather short formula for the function (22), the problem of minimization is solved analytically. According to the necessary condition for the existence of an extremum, let us set partial derivatives by parameters P_0 and P_1 to zero.

$$\begin{cases} \dfrac{\partial Q(P_0,\ P_1)}{\partial P_0} = \displaystyle\sum_{i=1}^{N} T_i^2 \left(-2\left(\frac{t_{0i}}{T_i} - P_0\right) - \left(\frac{t_{1i}}{T_i} - P_1\right)\right) = 0; \\ \dfrac{\partial Q(P_0,\ P_1)}{\partial P_1} = \displaystyle\sum_{i=1}^{N} T_i^2 \left(-2\left(\frac{t_{1i}}{T_i} - P_1\right) - \left(\frac{t_{0i}}{T_i} - P_0\right)\right) = 0. \end{cases}$$

$$\begin{cases} 2 \cdot P_0 \cdot \overline{T^2} + P_1 \cdot \overline{T^2} = 2 \cdot \overline{T \cdot t_0} + \overline{T \cdot t_1}; \\ P_0 \cdot \overline{T^2} + 2 \cdot P_1 \cdot \overline{T^2} = 2 \cdot \overline{T \cdot t_1} + \overline{T \cdot t_0}. \end{cases}$$

As a result, the system of two linear equations can be obtained

$$\begin{cases} 2 \cdot P_0 + P_1 = \dfrac{1}{\overline{T^2}} \cdot \left(2 \cdot \overline{T \cdot t_0} + \overline{T \cdot t_1}\right); \\ P_0 + 2 \cdot P_1 = \dfrac{1}{\overline{T^2}} \cdot \left(\overline{T \cdot t_0} + 2 \cdot \overline{T \cdot t_1}\right). \end{cases}$$

We solve this system by Cramer formulas according to which a system of two simultaneous equations in two variables P_0 and P_1, matrix determinant that is not equal to zero

$$\Delta = \begin{vmatrix} 2 & 1 \\ 1 & 2 \end{vmatrix} = 3 \neq 0$$

and determinants

$$\Delta_0 = \begin{vmatrix} \dfrac{2 \cdot \overline{T \cdot t_0} + \overline{T \cdot t_1}}{\overline{T^2}} & 1 \\ \dfrac{\overline{T \cdot t_0} + 2 \cdot \overline{T \cdot t_1}}{\overline{T^2}} & 2 \end{vmatrix} = = \frac{4 \cdot \overline{T \cdot t_0} + 2 \cdot \overline{T \cdot t_1} - \overline{T \cdot t_0} - 2 \cdot \overline{T \cdot t_1}}{\overline{T^2}} = \frac{3 \cdot \overline{T \cdot t_0}}{\overline{T^2}}$$

$$\Delta_1 = \begin{vmatrix} 2 & \dfrac{2 \cdot \overline{T \cdot t_0} + \overline{T \cdot t_1}}{\overline{T^2}} \\ 1 & \dfrac{\overline{T \cdot t_0} + 2 \cdot \overline{T \cdot t_1}}{\overline{T^2}} \end{vmatrix} = = \frac{2 \cdot \overline{T \cdot t_0} + 4 \cdot \overline{T \cdot t_1} - 2 \cdot \overline{T \cdot t_0} - \overline{T \cdot t_1}}{\overline{T^2}} = \frac{3 \cdot \overline{T \cdot t_1}}{\overline{T^2}}$$

have closed-form solution

$$P_0 = \frac{\Delta_0}{\Delta} = \frac{3 \cdot \overline{T \cdot t_0}}{3 \cdot \overline{T^2}} = \frac{\overline{T \cdot t_0}}{\overline{T^2}},\ P_1 = \frac{\Delta_1}{\Delta} = \frac{3 \cdot \overline{T \cdot t_1}}{3 \cdot \overline{T^2}} = \frac{\overline{T \cdot t_1}}{\overline{T^2}} \quad (23)$$

$$P_2 = 1 - \frac{\overline{T \cdot t_0} + \overline{T \cdot t_1}}{\overline{T^2}}. \quad (24)$$

4 Results

Table 2 provides statistics on the work of accountable BELAZ open-pit trucks in PJSC "Central GOK" open pit in 2015 (from the first mining workshop four trucks with utility numbers of 324, 325, 326, 327 were selected to facilitate parametric identification).

Given the average values of the parameters in table 2 which were determined with the aid of formulas (23) and (24), we obtain the probability values of an open-pit truck being in the state of operation, scheduled maintenance and unscheduled operating repairs respectively.

$$P_0 = \frac{\overline{T \cdot t_0}}{\overline{T^2}} = \frac{62020800}{76737600} = 0{,}808;$$

$$P_1 = \frac{\overline{T \cdot t_1}}{\overline{T^2}} = \frac{8168700}{76737600} = 0{,}106;$$

$$P_2 = 1 - P_0 - P_1 = 1 - 0{,}808 - 0{,}106 = 0{,}086. \quad (25)$$

Following the indication on the technical manual [12] for BELAZ open-pit trucks, specified values of probabilities of vehicles being in the state of operation, scheduled maintenance and unscheduled operating repairs have the form respectively

$$P_0 = \frac{7200}{8760} = 0{,}822;\ P_1 = \frac{900}{8760} = 0{,}103;$$
$$P_2 = \frac{660}{8760} = 0{,}075, \qquad (26)$$

which are sufficiently close to the corresponding values of parametric identification (25).

The obtained values of probabilities (25) allow for the conclusion that the mathematical model of the system of technological automotive transport is sufficient. The analysis of the function (22) indicates its nonlinear dependence on the parameters whose values are optimized. As a result, it was decided to apply a numerical approach [13] to solve the problem of minimizing the function (21) which involves minimizing discordances λ^*=0,00003015; μ_1^*=0,0002289; μ_2^*=0,057; ω_1^*=0,006; ω_2^*=0.

Besides appropriate possibilities

$$P_0 = P_0(\lambda^*,\ \omega_1^*,\ \omega_2^*,\ \mu_1^*,\ \mu_2^*) = 0{,}808,$$
$$P_1 = P_1(\lambda^*,\ \omega_1^*,\ \omega_2^*,\ \mu_1^*,\ \mu_2^*) = 0{,}106 \qquad (27)$$

align with parametric identification results (25).

Table 2. Data for the operation of accountable BELAZ open-pit trucks at PJSC "Central GOK" to parametric identification

Truck N0, *i*	Truck utility number	Technological state observation time for *i*-th truck, T_i, running hours	Total actual time t_{ki} when *i*-th truck is in each of the three technological states during period T_i, running hours			T_i^2	$T_i \cdot t_{0i}$	$T_i \cdot t_{1i}$
			t_{0i}	t_{1i}	t_{2i}			
1		8760	6950	940	870	76737600	60882000	8234400
2		8760	7100	880	780	76737600	62196000	7708800
3		8760	7120	930	710	76737600	62371200	8146800
4		8760	7150	980	630	76737600	62634000	8584800
Average values		8760	7080	932,5	747,5	$\overline{T^2}$=76737600	$\overline{T \cdot t_0}$=62020800	$\overline{T \cdot t_1}$=8168700

5 Conclusion

Consider the obtained convergence of specified (26) and numerically calculated values of the STAT parameters (25) and (27), it may be deduced that an adequate mathematical model of the system of technological vehicles is synthesized, which is quite possible to apply for open-pit trucks operation optimization.

The calculated optimal controlling actions in the form of the intensity of planned measures towards open-pit trucks allow developing a technique for dynamic adjustment of maintenance parameters, diagnostics and repair of BELAZ open-pit trucks, which will become the foundation for a sustainable future of industrial transport operation.

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Sustainable futures in the context of architectural design of hospitals

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Abstract. The problems of necessity of sustainable and ecological approaches in architectural design of hospitals are raised in the research. The best international experience of designing and operating hospitals designed on the principles of sustainable development is considered. Examples and implementation examples of healthcare institutions integrating energy efficient technologies are analyzed and illustrated: natural ventilation, solar panels, rainwater collection, filtration and reuse of wastewater, greening of the roof and walls, sun protection, aerodynamic volumetric and spatial form. Studying and using the proven experience of the best examples of ecological hospital buildings, recognized and certified at the highest levels of the world institutions for the development of a sustainable future, will allow Ukraine to create the conditions for solving the crisis both in the sphere of health care and in the ecologically preserved environment of the country.

1 Introduction

In modern civilization, nearly half of the total energy consumption in developed countries falls on architectural buildings and a fourth on transport. From this point of view, the role of the architect in the design of buildings for various purposes, including medical, in the issue of a sustainable future world, individual state or human settlement, is quite significant. Undoubtedly, only architects are unable to solve all the diversity of the world's environmental problems [1-3]. The architect, as the creator, has the opportunity to design innovative buildings that are able to use the minimum amount of traditional energy sources, providing their own needs with the help of renewable natural energy (Fig. 1, Fig. 2). Also, thanks to rational and proper urban planning, the architect is able to influence and correct traffic flows, reducing the negative impact on the already polluted environmental situation, particular in Ukraine.

Starting from the location and functional purpose of the building, the choice of its structural system, flexibility, technological resources of construction and subsequent operation, orientation at the site of design, and ending with the selected planning and volume-space form, engineering (heating, conditioning, characteristics) building materials – all this set of parameters chosen by the architect directly affects the amount of energy required for construction, operation and subsequent technical maintenance of building [4-6]. Outlined issues are of particular importance in the context of designing healthcare facilities in Ukraine. This is due to the prolonged economic and energy crisis in our country, as well as the fact that most of the architectural and urban system of medical establishments in Ukraine was built in a typical industrial way in Soviet times and today in all respects contradicts energy-efficient requirements as domestic and the world (Fig. 3, Fig. 4, Fig. 5) [4-7]. Build on the ongoing reform of the Ukrainian medical system, the issue of finding and using sustainable architectural solutions in the reconstruction and new development of medical facilities of any scale is becoming increasingly relevant. Therefore, an understanding of the harmony of the environment and the modern architecture of healthcare facilities should be reflected in the emergence of health care projects that integrate best practices in energy-efficient construction, opening a new page in the evolution of architectural design in health care facilities and in the overall history of world design and construction.

Fig. 1. The Crystal, Wilkinson Eyre Architects, London.

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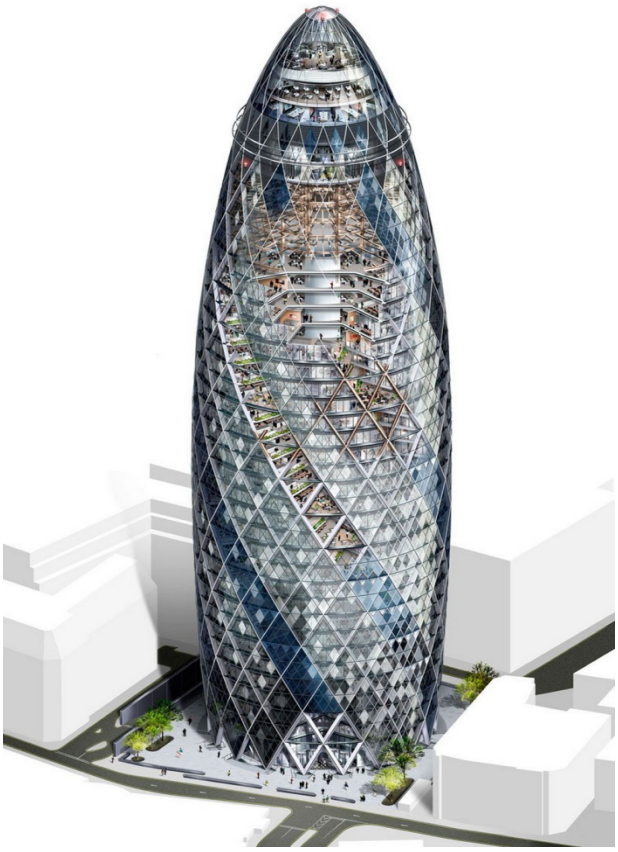

Fig. 2. 30 St Mary Axe / Look Inside, Foster + Partners.

Fig. 3. Kyiv City Clinical Oncological Centre.

Fig. 4. Hospital building No.3, Kryvyi Rih.

Fig. 5. Children's Hospital No.2, Kryvyi Rih.

2 Statement of the main material

Today our country is dependent on energy imports, ensuring affordable and reliable energy supply is a political priority for Ukraine. In Ukraine, energy consumption, the ratio of energy consumption to energy production, is about three times higher than in EU countries. Obsolete infrastructure and energy supply systems, as well as dependence on energy imports from abroad, have led to a significant increase in energy prices of [8-11]. In this aspect, the issue of accessibility and security of energy supply has become a priority for the Government of Ukraine, which primarily supports energy savings in the budget sector. The most energy-intensive public facilities include more than 1,000 Ukrainian hospitals with nearly 430,000 beds. Some hospitals spend up to 20 percent or more of their budget on energy. The outlined situation means that healthcare institutions are under pressure from high energy prices. First of all, the quality of medical services suffers from this: hospitals cannot buy important medical products in sufficient quantity, upgrade equipment, carry out modernization and reorganization, and engage in research activities.

In order to reduce costs, hospitals should conserve energy reasonably and where appropriate. The recent rapid rise in energy prices has led to significant economic pressures on health care facilities and limited their financial capacity, leading to a decline in the quality of health care services [12-14]. Due to considerable energy consumption, hospitals do not always manage to reach patient comfort standards and indoor temperatures remain too low in winter. Energy upgrades, mainly involving no or small investments, are not currently being implemented. The potential for energy savings in hospitals is generally high, but hospital staff often lack the resources and knowledge to implement it. In addition, there is a lack of consultation on energy efficiency and financial capacity [15-20]. Therefore, considerable attention should be paid to the energy aspect of the sustainable development of architectural solutions.

From the perspective of sustainable future architecture for reconstruction and new development at Ukrainian healthcare institutions, it is advisable to refer

to the design and operation experience of architectural-environmental complex of Ng Teng Fong Innovative Singapore Hospital (NTFGH) and Jurong Public Hospital (JCH), which have received numerous awards in energy competitions, ratings and certifications and energy efficiency and certification designing health facilities worldwide (Fig. 6).

Fig. 6. General view of the hospital complex Ng Teng Fong (NTFGH) & Jurong (JCH).

Both hospitals, with a total capacity of 1,100 wards, are the first in the country to be built under the new mandate of the Ministry of Health of Singapore (part of the Progressive Health Master Plan 2020), aimed at providing the state with patient-centred services in a comprehensive mode, that is, by combining emergency services and outpatient specialities with a general public hospital. In this sense, the complex of NTFGH and JCH hospitals, functionally and planning integrated within one territorial area, serves as a good model for both Ukrainian architects and health care organizers in the context of the global trend of combination and concentration in one building spectrum of medical services (primary, secondary and tertiary levels of medical care) (Fig. 7) [19-22].

Fig. 7. Accommodation of the hospital complex Ng Teng Fong (NTFGH) & Jurong (JCH) in the urban area.

NTFGH 8th- and 16-story Regional Emergency Hospital and 12-story JCH Hospital, designed to assist and provide long-term rehabilitation and palliative care, built at 2015 in a beautiful 1.9 million-square-foot urban area feet. Delivering energy intensity (EUI) of 72 kWh per square foot per year, the innovative energy-efficient design of the hospital complex reduced energy costs by 38 percent compared to other Singapore hospitals and 69 percent less than the average US hospital. Designed according to Singapore's Green Mark Platinum standards, which certify buildings based on energy efficiency, water efficiency, environmental protection, indoor environment quality and other environmental features – the project was awarded one of the COTE Top 10 awards by the American Institute of Environmental Architects (COTE). The Top Ten Award recognizes the sustainable development of design around the world and confirms that the project meets COTE criteria for social, economic and environmental value. It should be noted that Ng Teng Fong and Jurong Hospitals have become one of the few health projects to receive this award.

The design features of the NTFGH and JCH hospital complex was developed using the key-principles of sustainable architecture include design approaches below. They include a well-considered design approach to the specific characteristics of the external environment, the ability to individually open windows and the natural ventilation of wards, depending on patients' wishes. Both hospital buildings are equipped with 90 kW photovoltaic arrays, specially designed to compensate for illumination of the treatment facility, as well as heat recovery, heat pumps and heat exchangers with streamlined coils to maintain the required operating temperatures. The cooling system's metering and monitoring system monitor current energy use, solar thermal collectors provide 100 percent of hot water demand, and the filtration system treats wastewater for reuse. The hospital complex uses rainwater collection, LED lighting, daylight and occupancy sensors, a building management system with monitoring, occupancy levels and sleep modes to save energy. Each ward on NTFGH and JCH floors with good window views is linked to the geometry of the floor plans (Fig. 8). Each floor of the Singapore hospital complex, unlike the traditionally Ukrainian linear rectangular geometric solutions, received fan-shaped shapes, with bed placements being calculated and rotated at an individual angle, thus providing communication through a window opening overlooking the street (Fig. 9, Fig. 10).

Ultimately, the unique aerodynamic shape of the hospitals, combined with unidirectional corridors and funnel-shaped floor profiles, maximizes wind flow. Special consideration should be given to the regional features of the area, which managed to achieve natural ventilation for 70 percent of the buildings of the hospital – the team of architects took into account the presence of breezes characteristic of the area during the two-year monsoon seasons in Singapore. Thus, the individual volumetric shape of the NTFGH and JCH hospitals, combined with the aerodynamic modelling of the projections of the overlapping floor slabs and the calculated distances between the window openings on both sides of the wards, made it possible to provide efficient and free ventilation with natural wind flows. The result is also that 82 percent of hospital hospitals are passively cooled and naturally ventilated with a small

percentage of mechanical ventilation coming from ceiling and exhaust fans. During the fog season in Singapore, the windows of hospitals are closed and both buildings use a centralized air filtration system. The integration of the naturally ventilated design of the hospital complex has reduced mechanical cooling by 70 percent, as well as installed smaller cooling towers that use filtered wastewater and selected water from the air-conditioning system, allowing for more cycles of water reuse.

Fig. 8. Fan-shaped outlines in the formation of floorboards and plans of the hospital complex Ng Teng Fong (NTFGH) & Jurong (JCH).

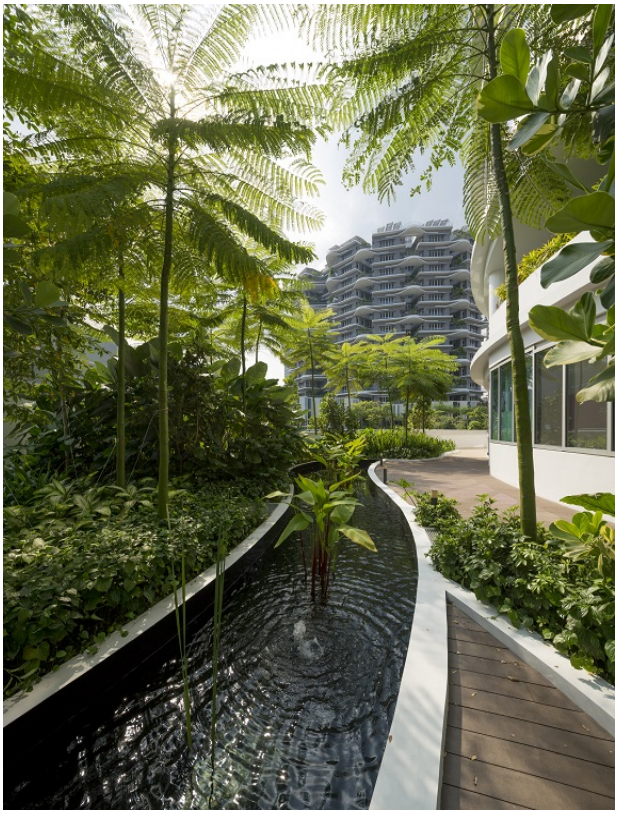

Fig. 9. Exterior and windows from the hospital complex Ng Teng Fong (NTFGH) & Jurong (JCH).

Fig.10. Exterior of hospital complex Ng Teng Fong (NTFGH) & Jurong (JCH).

In the case of hospital facilities design, the issue of the spread of hospital-acquired infections is of particular importance. In this sense, to design infectious control in the initial design phase, the architectural team used computer computing and simulation models to accurately determine wind flow directions and to ensure that the wind would not pass through several patients and spread infectious pollution. As a result, in the hospital wards, due to the correct size and location of the windows, it is ensured that the wind passed through the bed of only one patient before leaving the building. Another resolved design issue was that with a lot of daylight and ventilation coming into the hospital building, it was necessary to find “reasonable” shading to prevent sunlight and glare.

Architects took advantage of the geographical features of Singapore’s location near the equator and the position of the sun changes slightly throughout the year at all times of the year, making the sun’s shading plan relatively easy to create. The project envisages three levels of shading of the sun: large projections from concrete floor slabs, blinds with integrated horizontal and vertical slats, as well as the sun screens (Fig. 11, Fig. 12).

The latter provide shading for about 60 percent of the facades where patients’ wards and staff rooms are located. Also, the presence of vegetation on the roof and near the windows on several floors of both buildings is considered an element of theoretical shading, with the additional possibility of cooling the ambient temperature

inside the buildings, absorption and filtration of pollutants (Fig. 13, Fig. 14, Fig. 15, Fig. 16). Other sustainable environmental strategies used in NTFGH and JCH include water-saving plumbing equipment and rainwater accumulation systems that help to irrigate a large area of landscaping.

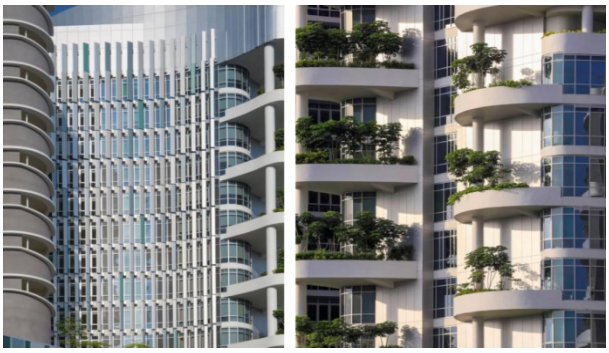

Fig. 11. Use of sunscreen in a hospital complex Ng Teng Fong (NTFGH) & Jurong (JCH).

Fig. 12. Sun blinds in hospitals interior Ng Teng Fong (NTFGH) & Jurong (JCH).

Fig. 13. Exterior view of hospital complex Ng Teng Fong (NTFGH) & Jurong (JCH).

Fig. 14. Active use of landscaping in hospitals Ng Teng Fong (NTFGH) & Jurong (JCH).

Fig. 15. Hospital in an urban environment.

Fig. 16. Implementation of green roofs.

3 Conclusion

Integration of principles of sustainable development in architectural design of hospitals is of particular importance for Ukraine – using leading foreign experience, advanced energy-efficient engineering, taking into account the regional geographic and climatic features of our area, the architect, as the main "conductor", has the opportunity to solve several problems at once. On the one hand, we are talking about the ecological spectrum of designing and construction of medical establishments (saving traditional energy sources, reducing the harmful impact on the environment, energy autonomy of the building, etc.), on the other – a significant economic effect and, as a consequence, the opportunity to spend saved financial resources. for the development and improvement of the healthcare sector. According to the successful example of sustainable design of a medical complex in Singapore, it is considered advisable to lay down project solutions that strict meet international standards for sustainable architecture at the design stage. However, in the reconstruction phase and within the limited budget, considerable attention should be paid to the following aspects. First, it is necessary to increase the energy independence of the buildings by providing them with alternative energy sources, in particular solar collectors, which can fully or partially (depending on the region and spatial characteristics of the complex) solve the issue of electricity consumption and space heating. As a great part of medical buildings in Ukraine have typical flat roof designs, this solution can be effectively implemented without significant intervention at the architectural and design-built system. The second aspect is the contextual relevance of the facade solution to the natural-climatic conditions of the planning region. In Ukraine is a long heating season, which necessitates the implementation of energy-efficient solutions like the facade warming and sealing the building by the corresponding indicators glazing. Another aspect is the rational use of water resources – the collection and using of rainwater, as well as the filtration system of used water, which allows for more cycles of its reuse. The fourth aspect is the provision of a natural independent ventilation system for each unit, which reduces the burden on energy consumption and improves the microclimate of the premises, which is necessary for successful treatment and healthcare care. The highlighted aspects are of paramount importance for the modernization of existing medical facilities and their consistency with sustainable design principles.

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Calculation of tube concrete elements with strengthened cores by numerical method

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Abstract. The paper considers the features of formation of finite element models of tube confined concrete structural elements in the form of centrally compressed rod with strengthened cores. The prerequisites, which underlies the proposed approach to the formation of finite element models of tube confined concrete elements with strengthened cores, are given. Lengthwise the tube confined concrete elements have constant dimensions and a set of cross-sectional components. It is proved that the use of high-strength concrete allows performing calculations in the elastic stage of the work of materials. When modeling the work of rod reinforcement in tube confined concrete elements with strengthened cores, it can be represented as an imaginary cylinder with a cross-sectional area equal to the area of the rod reinforcement. The proposed prerequisites for the numerical simulation of the work of tube confined concrete elements with the strengthened cores of the studied types allowed to construct adequate finite element models. The difference in the value of the load-bearing capacity obtained from the results of physical and numerical experimental studies was 5,94…7,72 %.

1 Introduction

Sustainable development of modern construction requires the use of compressed elements (columns, posts of various purposes), which would have a large bearing capacity. These requirements are fully met by tube confined concrete made up of steel pipes filled with concrete. Due to its numerous advantages (increased strength of concrete core due to volumetric stress state, lack of formwork during construction, significant savings of labour and energy during construction), tube confined concrete has become widespread in construction both in our country and abroad [1]. One of the disadvantages of tube confined concrete, which somewhat restrains its use, is the significant cost of steel, which increases the cost of construction [2]. However, with the use of strengthened cores, significant savings of steel can be made to create a shell, which will increase the technical and economic characteristics of the structure.

It is known that in compressed tube confined concrete elements the active force is perceived by both the tube shell and the concrete core [3, 4]. If in some way to increase the bearing capacity of the core, then it is possible to reduce the cost of steel for producing a tube confined concrete element with a predetermined bearing capacity [5]. Therefore, the use of a strengthened core will significantly reduce the cost of steel and save on construction.

The variety of possible combinations of the inner core and shell complicates the search for more rational combinations. Conducting experimental studies requires significant material costs. In such circumstances, it is advisable to use the possibilities of the numerical research.

The task was to develop the methods of estimation of the stress-strain state and the calculation of the load-bearing capacity of the compressed rod tube confined concrete structural elements using software complexes that implement the numerical method of the finite element method algorithm taking into account the volumetric stress state of the strengthened core.

World experience shows that deformation and other mechanical characteristics of tube confined concrete elements depend not only on geometrical parameters, but also on the composition of concrete [6] and the method of strengthening the core [7]. Considering such a number of factors requires the construction of complex mathematical models of the tube confined concrete resistance to the external load [8]. The examples of modeling the work of concrete elements by finite element method are known [9, 10, 11]. The models of tube confined concrete considered in these works do not cover different ways of strengthening the core.

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2 Main part

The reinforcement of the core of the concrete element significantly affects its work under load. The method of calculating the load-bearing capacity of such structures should take into account all these features. Therefore, it became necessary to develop recommendations for the assessment of stress-strain state and load-bearing capacity of tube confined elements with strengthened core.

The use of software systems that implement the finite element method for estimating the stress-strain state of load-bearing building structures allows to obtain more widely the fields of stress and strain distribution than is provided by experimental research methods. Establishing a stress-strain state upon reaching a certain limit state makes it possible to obtain the value of the load-bearing capacity of the load-bearing structure in the form of a tube confined concrete compressed rod.

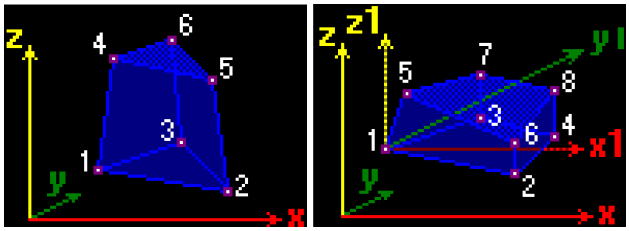
The calculation is based on the following prerequisites:
- the materials that make up the tube confined concrete element are considered as isotropic elastic-plastic;
- between stresses and strains in the materials of the tube confined concrete element, a linear dependence is reached upon reaching the first limit state in strength;
- throughout the deformation process, the longitudinal axis of the tube confined concrete element remains straight;
- the flat section hypothesis is considered valid;
- the geometric dimensions of the cross-section and the physical properties of the materials along the length of the tube confined concrete element do not change;
- we consider that the tube shell, the concrete core and the reinforcements are deformed jointly;
- static condition remains: the amount of effort on the longitudinal axis is zero;
- the tube shell works in a flat stress state; the concrete core – in the bulk; additional rod reinforcement – in the unconfined compression.

2.1. Calculation of stress-strain state of compressed elements

The calculation of the stress-strain state and the structural evaluation by numerical method were performed using the SCAD software complex, which implements the finite element method algorithm. Structurally, the model of the prototypes is selected as a complex body [12]. That is, prototypes are presented in the form of enlarged blocks: cores and outer shell (Series I); cores, outer shell and additional core reinforcement (Series II); annular cross-section cores, outer shell and fill (Series IIIa); annular cross-section cores, inner and outer shells and fill (Series IIIb).

In forming the finite element scheme, spatial elements of two types were used: hexagonal (Fig. 1a); octagonal (Fig. 1b).

The design scheme is designed to completely replicate experimental studies. Thus, the bottom base is fixed from vertical displacements (Z axis). That is, on the node points of the lower edge of the calculation model ligatures of several types are put. Ligatures are placed at the centre point, which prevents it from moving in the direction of the coordinate axes (X, Y and Z axes).



a) b)

Fig. 1. Types of the finite elements.

The load is transmitted to the upper edge of the prototype. The direction of action of the load corresponds to the direction of the Z axis. The load is applied through a three-dimensional rigid body.

The rigid body master node is located on the longitudinal axis of the prototypes (Fig. 2).

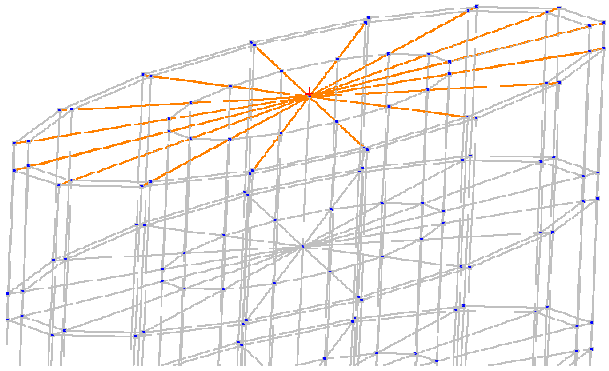


Fig. 2. The rigid body characteristics.

2.1.1 Calculation of tube confined concrete elements of group I

Experimental studies of tube confined concrete elements with a core made of high-strength concrete have proved that, by the moment of in the shell, the last of the concrete core works in parallel. Therefore, when developing a methodology for assessing the stress-strain state of such structures, we believe that the tube shell and concrete core work in parallel until the yield of the tube shell begins. Subsequently, the concrete core and shell work together.

The outer shell of the first series samples is an empty cylinder and the cores are a solid cylinder. The outer surface of the core and the inner surface of the shell are common. Therefore, when forming a finite element model, joint node points are introduced on this surface. The shell consists of rectangular spatial finite elements (Fig. 1b) – 16 elements along the perimeter and 16 elements in height (Fig. 3). Two types of spatial elements (Fig. 1) were used to model the core. The load was transmitted to the element through a rigid die (Fig. 2).

The final appearance of the finite element model of tube confined concrete elements with cores of high-strength concrete is shown in Figure 3.

2.1.2 Calculation of tube confined concrete elements of group II

In structural form, the difference between the elements of this type is the presence of core reinforcement in the body of the core. As noted, the rod reinforcement strengthens the resistance of the concrete core in the longitudinal direction, but in the transverse direction it does not work. Therefore, in order to model such an element of the prototype, it is proposed to represent the core reinforcement in the form of an imaginary shell. The final elements that make up this imaginary shell are flat rectangular plates with orthotropic properties. The geometric characteristics of the imaginary shell are characterized by: diameter D_{s1}; thickness t_{s1}. The rod reinforcement is located around the ring, so the diameter of the imaginary shell is equal to the distance from the vertical axis of the tube confined concrete element to the longitudinal axis of the rod reinforcement. The thickness of the imaginary shell A'_{s1} is calculated provided that the area of the core reinforcement A_{s1} is equal.

2.1.3 Calculation of tube confined concrete elements of group III

The prototypes of the third series are the most complex. By design, they are divided into two subgroups. Thus, samples of group IIIa consist of two or three components: a steel outer tube shell; centrifuged concrete cylinder with cavity; concrete solid cylinder.

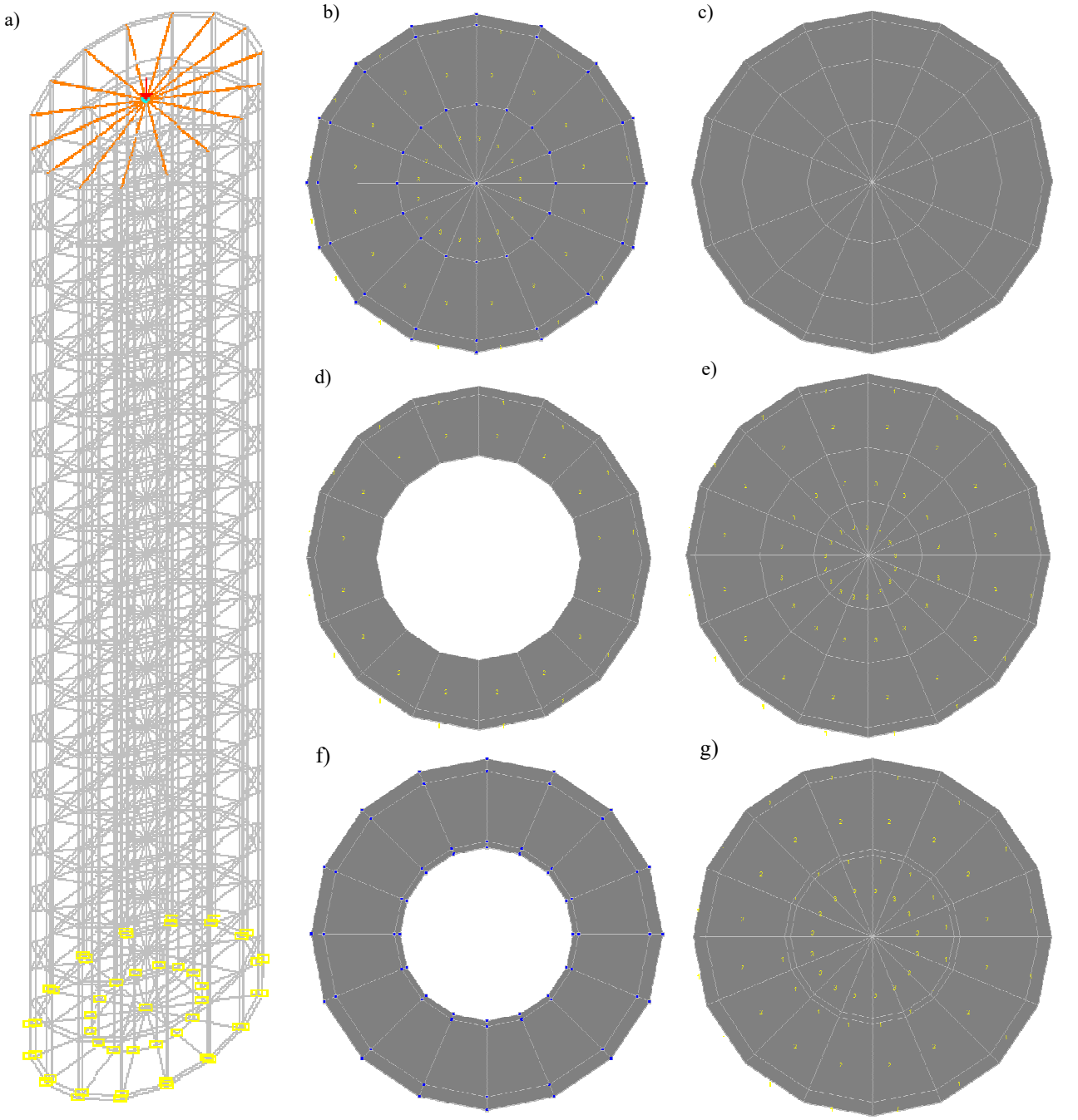


Fig. 3. The general finite element model of the prototypes (a) and cross sections of the prototypes: b – series I; c – series II; d – series TC-IIIa-I-I; e – series TC-IIIb-II-I; f – TC-IIIb-II-I; g – TC-IIIb-II-II.

The two-component tube confined concrete element of the annular section is modeled with the help of octagonal three-dimensional elements (Fig. 1). The load is applied to the upper edge, but the outer surface of the steel tube shell and the inner surface of the centrifuged concrete cylinder with the cavity remain unloaded. On the common surface at the node points they are connected. The lower edge is covered with ligatures that restrict the movement of the corresponding node points of the finite element model along the Z axis.

The cross-section of the three-component tube confined concrete elements of the circular cross section of group IIIa includes a fill made of concrete but with other mechanical properties. Therefore, the cross section has finite elements of three types of rigidity. Hexagonal volume finite elements were used to model the filling.

A structural feature of the tube confined concrete elements of the annular section of subgroup IIIb is that the cores are divided into two zones: outer and inner. This division is made by introducing an additional tube shell. The outer and inner tube shells and the concrete layer between them are modeled by octagonal three-dimensional elements. The filling of the cavity of the inner tube is modeled by hexagonal volume elements. The load was applied to the upper edge through a rigid die. The center point of the lower edge is covered with ligatures, making it impossible to move along the X, Y, Z axes. Other lower edge node points were able to move along the X, Y axes.

2.2 Calculation of the bearing capacity

The download was done in steps of 0.1 by N1. The corresponding experimental value was accepted as the destructive effort of N1. Upon reaching 0.8·N1, the loading rates were assumed to be 0.05 from N1. According to the results of experimental and numerical studies, the graphs of the development of longitudinal deformations were constructed.

As the bearing capacity of the tube confined concrete elements with strengthened core of all types studied, take the amount of external force that corresponds to the beginning of the steel yield of the outer tube shell. For the purpose of unification in numerical studies, this moment was recorded by the achievement of longitudinal relative deformations of the value 200×10^{-5}.

The results of the calculation of the bearing capacity of tube confined concrete elements with strengthened cores of all three series are shown in Table 1.

The method of supporting the extreme edges of the prototypes significantly influenced the results of evaluating the bearing capacity by the numerical method. In the SCAD software package, it is possible to provide various fixing methods. So, in the course of numerous experiments, the node points of the upper and lower edges could be fixed from linear and angular movements. For this, ligatures are introduced. The presence of ligatures from angular displacements leads to the appearance of additional force factors that did not appear during the physical experiment. Therefore, these types of ligatures were not used at all. Linear ligatures were set in the direction of the three coordinate axes. Figure 4 illustrates how the number of linear ligatures at each node point affects. So, when the node points of the extreme edges are fixed in the limiting state, the prototype was deformed in the form of a "barrel" (Fig. 4, a). If to establish restrictions on the linear displacements of the node points of the extreme edges along the longitudinal axis Z, then in the process of deformation it seems to only increase the thickness (Fig. 4, b). This type of deformation is more consistent with the results of physical experiments.

Table 1. The comparison of the results of experimental and theoretical studies.

Series of prototypes	**Bearing capacity (N_1), *kN***			**Difference, %**	
	experimental, N_1^{exp}	theoretical subject to the elastic work of concrete, N_1^{teor1}	theoretical subject to the plastic work of concrete, N_1^{teor2}	N_1^{exp} and N_1^{teor1}	N_1^{exp} and N_1^{teor2}
TC-***I***-11	652	721	694	10,6	6,4
TC-***I***-12	716	768	739	7,2	3,2
TC-***I***-13	869	922	894	6,1	2,9
TC-***I***-21	1840	2066	2009	12,3	9,2
TC-***I***-22	2100	2230	2207	6,2	5,1
TC-***I***-23	2400	2566	2582	6,9	7,6
TC-***I***-31	2970	3273	3196	10,2	7,6
TC-***I***-32	3386	3694	3572	9,1	5,5
TC-***I***-33	3636	3832	3789	5,4	4,2
TC-***II***-11	1080	1176	1149	8,9	6,4
TC-***II***-12	1310	1357	1359	3,6	3,7
TC-***II***-13	1490	1568	1542	5,2	3,5
TC-***IIIa***-I-I	4075	4536	4450	11,3	9,2
TC-***IIIa***-II-I	4425	4753	4691	6,0	7,4
TC-***IIIb***-II-I	1420	1536	1522	8,2	7,2
TC-***IIIb***-II-II	1800	1913	1908	6,3	6,0

In addition, it should be noted that the appearance of such corrugations in the supporting zone significantly increases the stress in the tube shell compared to the middle (in height) section. Such an excess reaches 15 – 20%. As a consequence, the bearing capacity of the tube confined concrete elements with strengthened cores is reduced in numerous experimental studies. Therefore, the studies used only ligatures along the Z axis.

Characteristic distribution of stresses on the body of the prototype according to the results of numerical experiments is shown in Figure 5. Figure 6 shows the characteristic distribution of deformations on the tube confined concrete element with strengthened cores.

2.3 Comparison of calculation results with experimental data

Numerical modeling allows for a broader analysis of the stress-strain state and bearing capacity of

compressed bearing structures. In addition, it is possible to carry out an infinite number of studies of structures with different physical and mechanical properties of the materials used and under different types of loading. That which is practically impossible to carry out by physical experiment. But the success of numerical experimental studies is only possible with adequate modeling.

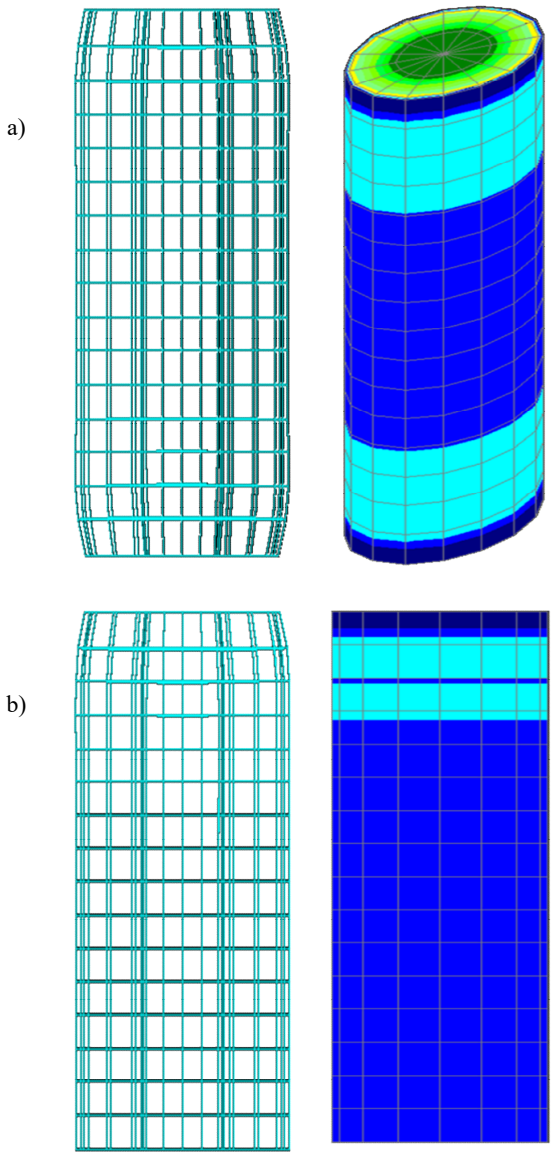


Fig. 4. The analysis of the methods to fix the upper and the lower edges of the prototypes.

In conducting the numerical studies, a number of prerequisites were put forward, which are given in the beginning. Some of these conditions were accepted based on the results of experimental studies and some based on logical considerations. In order to evaluate the degree of importance of these assumptions, the paper compares the values of the bearing capacity obtained from experimental studies with the results of numerical studies on finite element models of the respective prototypes. The theoretical value was calculated by two basic assumptions: the core concrete works as elastic or elastic-plastic material.

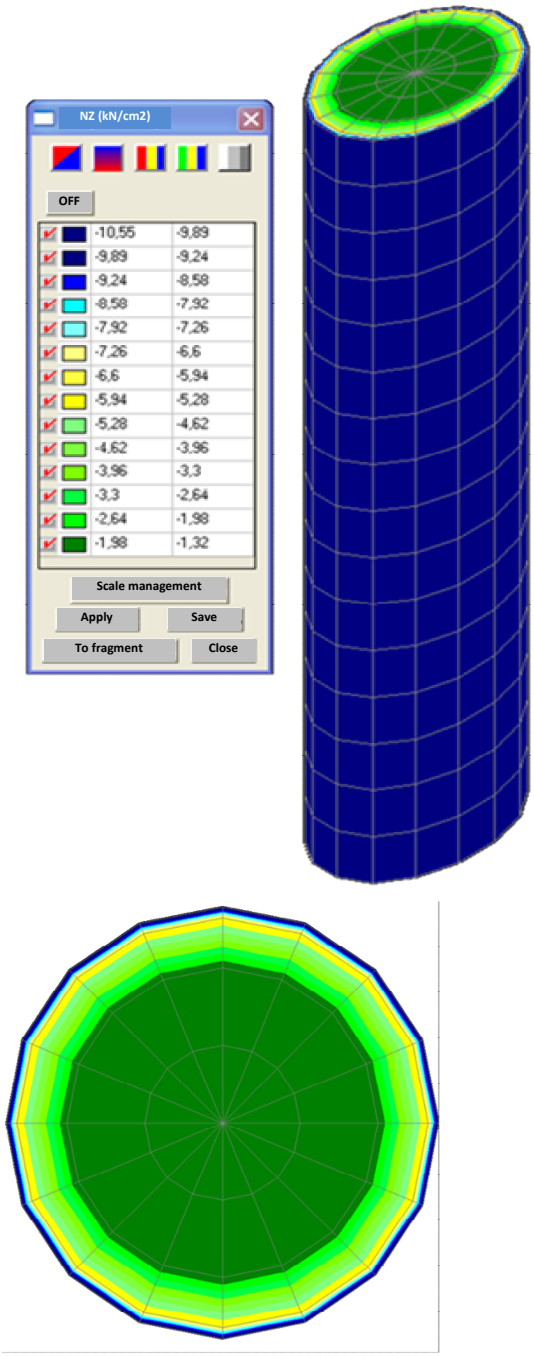


Fig. 5. The distribution of stresses through the tube confined concrete element with strengthened core of series TC-I-22

The results of the comparison of the bearing capacity of the prototypes of groups ***I, II, III*** are shown in Table 1.

When the core material works as elastic, the difference between the experimental and numerical results is on average 7.72%. Taking into account the elastic-plastic properties of the core concrete – the average difference was 5.94%.

3 Conclusions

Based on the results of numerous studies, the following conclusions can be drawn:

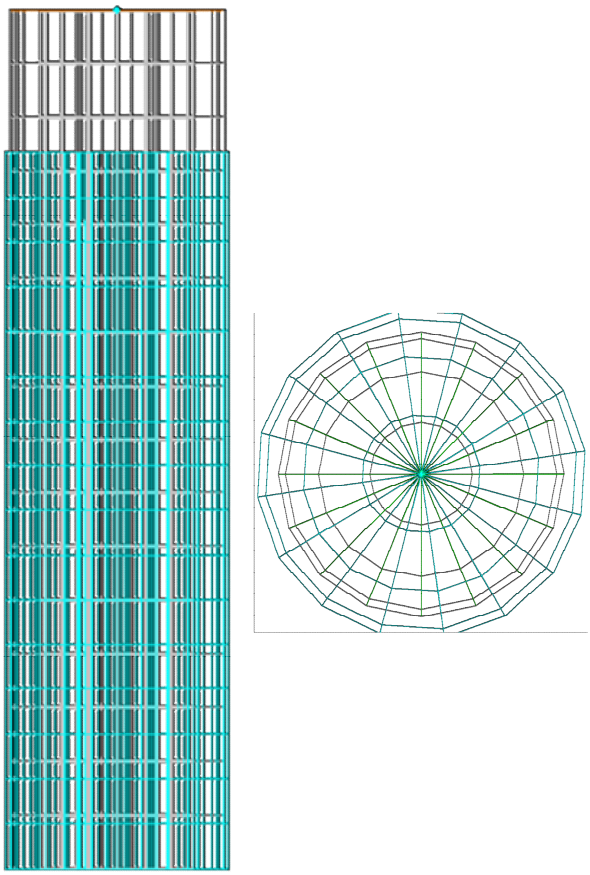


Fig. 6. The distribution of deformations through the tube confined concrete element with strengthened core (group I)

1. With numerous studies of short tube confined concrete elements with strengthened core, it is necessary to provide for the possibility of free movement of the node points of the extreme edges of the finite element model in its plane.
2. When modeling the work of rod reinforcement in tube confined concrete elements wit strengthened core, it can be represented as an imaginary cylinder with a cross-sectional area equal to the area of the core reinforcement. The mechanical properties of such a cylinder should have an orthotropic character.
3. When using high-strength concrete as the core of tube confined concrete elements in numerical studies, it can be considered that they work elastically at all stages of work under load, up to the time of reaching the limit state.
4. The proposed prerequisites for numerical modeling of the work of tube confined concrete elements with strengthened cores of the studied types allowed to construct adequate finite element models. Thus, by comparing the results of physical and numerical experimental studies, the difference between the corresponding bearing capacity was 5.94… 7.72%. The coefficient of variation is 0.78.

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Sustainable development and harmonization of the architectural environment of cities

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Abstract. The article emphasized the necessity of preserving spiritual values in the process of sustainable development of cities and urban communities. The article considered harmonization of the architectural environment as the ultimate goal and the defining condition for sustainable development of settlements. Basing on the principles of urban synergetics proposed to use internal reserves as well as the self-organization potential of the population and urban planning effectively redistributes resources and reserves. The article deals with the main provisions of the architectural environment harmonization theory with the consideration of different ideas of harmony, the importance of achieving correspondence between a person's world-view and his surroundings, the expediency of taking into account interpersonal interactions between members of society. The strategic directions of penitentiary environment improvement at all organizational levels outlined. It proposed to form multi-level public spaces for recreation and communication of residents in the centers of historical cities where there is not enough free space. The ways to use recycled materials products for the buildings and structures construction, urban areas improvement, equipment manufacturing were been outlined.

1 Introduction

The UN conferences on the future of humankind recognized problems of sustainable development of cities and urbanized territories, the humanization of the man artificial environment in a too pragmatic era of total globalization as major issues (Stockholm, 1972; Istanbul, 1996; Johannesburg, 2002; Rio de Janeiro, 1992, 2002, 2012, etc.). However, in addition to the material component of this environment, one should pay attention to the spiritual values of urban culture, since society recognizes "cities and towns as centers of civilization, generating economic development and social, cultural, spiritual and scientifical advancement" [1, item 2].

Among these values, the special emphasis placed on the desire to reconcile the existing "chaos" of entirely urbanized territories and the "cosmos" of historic cities to harmonize the architectural and urban environment at all levels and stages of its integrated development. This development must be focus not only on the economical and the efficient use of resources but mainly on the maximum using of internal reserves and urban development potentials as well as urban residents' activities. This activity ultimately contributes to the integration and harmonicity of sustainable development. It is the harmonization, as the protection and reconciliation of the material and spiritual goals and values of the urban communities in the self-organization processes, that, in the end, reveals the potential and the hidden internal reserve of sustainable development.

2 Formulation of the problem

The key to achieving the global Sustainable Development Goals is the harmonization of national strategies of economic growth, social integration, and environmental protection [2]. Ukraine's progress in these strategic directions significantly complicates by the painful problems of Ukrainian society. There are include the low efficiency of available material and intangible resources use; lack of efforts to strengthen ties between members of the society; low level of tolerance towards those who are on the sidelines of social life; lack of attention from both the authorities and the citizens to the maintenance of environmental balance in urban areas.

Experts in different fields of knowledge are searching for ways to overcome these and other obstacles for a prosperous future. For example, Ukrainian architects see the following perspectives:

• Achieving consistency between the evolution of urban systems and the synergistic principles of harmonical development.
• Consideration of socio-psychological characteristics of the population different categories in the organization of the architectural environment of settlements.

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• The penitentiary environment improvement at all levels from the territorial network to the arrangement of the separate premises of establishments.
• Creating optimal conditions for various forms of leisure, recreation, communication between residents in the city areas that lack space for this purpose.
• Cardinal change in citizens' attitudes towards waste recycling and the introduction of advanced resource reuse technologies.

3 Ways to enhance the architectural environment sustainability in cities

3.1 Self-organization and sustainable development of the urban environment

Recently, the problem of finding and identifying untapped potentials and reserves of urbanization has attracted the attention of many professionals and international organizations seeking cooperation. The UN documents suggest "... enhancing inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries" [2, item 11.3] by 2030. In 20th century modern architecture and urban planning, the problem of harmonization, as an important factor and potential for integrated development of the environment, has received impetus for a solution, starting with F. L. Wright's research utopian projects. In his work, the eminent architect focused on the fact that "… modern homes and cities … must have the kind of harmony that any well-balanced mechanism has, but such harmony, however advanced it might be at the moment, is, above all, only the foundation of beauty – the promise of its possibility" [3, p. 72]. Many other architects – Le Corbusier, L. Mies van der Rohe, A. Aalto, E. Saarinen – were involved in these studies and discussions, extending and deepening the concept of harmony from the point of view of the proportion of the environment, enhancing its social, ecological, aesthetic and other humanistic values and qualities.

At the turn of 20th and 21st centuries, architects and urban planners in science and practice have increasingly paid attention to the problems of the urban environment harmonization at all levels of its development – planetary and state, regional and local. It is enough to mention the Ekistics and the concept of the Eikumenopolis – K. Doxyadis's planetary city. The quintessence of this theory was the creation of a global urban environment of "universal happiness" for all people on the planet without exclusions [4]. K. Lynch, who believed that the aesthetic qualities of the city and region environment were the leading ones, added to these humanistic demands: "... undoubtedly, we need an environment not only satisfactorily organized, but also with symbolic color and poetic content. It should speak about the individual and about society as a whole, about historical traditions and dreams about the future, about the natural environment and about the complex functional nature of cities" [5, p. 112].

In some studies, the ideas of harmonizing the planning structure of the city implemented with the help of harmonic rows of the golden section [6]. This unique proportional system, which focuses on the maximum economy and conservation of resources in the creation of objects of living and inanimate nature, as well as in the aesthetic perception of the architectural environment, has been fully utilized in yet another direction of urban planning theory – in urban synergetic [7]. The analysis of the self-organization of the urban population showed that the processes of cities' sustainable development accompanied by the redistribution of the volumes of transport and pedestrian work of the population in accordance with harmonic rows of the golden section. This has allowed harnessing the self-organization potential of the population and urban planning at some stages of the city's development as well as directing this internal reserve and resource savings to harmonize sustainable development.

The harmonization, as any process of natural development, based on its undulating nature with "downturns" and "ascents" of urban activity and activity of urban residents. This creates the preconditions for the accumulation and saving of internal resources in some periods so that at other stages of urban development, they can spent as efficiently as possible to maintain its sustainability. The range of sustainable development includes ultra-short waves of transformations of the architectural environment, short waves of changes in modes of urban development, medium waves of historical city development, and long waves of evolution. The one-generation life of residents identify as the primary parameter humanizing the city's sustainable development. At the same time, the community of urban dwellers divided into four communities – townsfolk, settlers, urban people and colonists – who perceive the space-time of the city in different ways, and, accordingly, have the opportunity to form the most suitable for themselves environment.

In the area of urban synergetic, a system of genre design proposed to harmonize these environments. In a self-organizing and participatory movement, in which specific urban communities work closely with urban planners, designers, and managers, there is an opportunity to create a fully-fledged and harmonious urban environment at every stage of sustainable development, with broad involvement of its potentials, including artistic and aesthetic. In the genre of architectural topic, the community of townsfolk, for whom the past is most important, finds a complete set of means of harmonization to reproduce the historical traditions of urban culture. The genre of architectural rhetoric that helps artistically respond to the current challenges of today is best suited to the settlers, who prefer to solve today's problems. Urban people, with the priority of the future, focus on the architectural topic, which allows one to look into the near future with the help of artistic images and symbols similar to literary tropes (metonymy, metaphor, etc.). For colonists, with their uncertainty about the passage of time, it is important to find new utopian images and symbols of the distant future that contribute to the prediction and

forecasting of paths for further sustainable development. That is why architectural poetics will suit their preferences.

From the standpoint of urban synergetic, the future of urban development unconditionally linked to the use of internal reserves and potentials of self-organization processes, the naturalness of which is closely linking to their fluctuating nature and the effective redistribution of resources and reserves, including artistic and aesthetic, at all stages.

The use of all the reserves and potentials of sustainable development is a leading factor in the study of effective methods and means of harmonizing the architectural environment at all levels of the current city organization.

3.2 Architectural environment and sustainable development of urban communities

Maintaining harmony between people and the environment is a major outcome of the global sustainable development strategy. The lack of unanimity in the interpretation of harmony, narrow profile consideration of the architectural environment, as well as the widespread shift of focus from person to society or to a separate part of it significantly, complicate the realization of this intention.

The architectural environment is the object of study, which allows seeing all aspects of the city in their syncretic unity, and tracing the peculiarities of its transformation in interaction with the person in its individual, collective and social manifestations. Recognition of the right to life and self-realization for each person in the best possible conditions are forces to refrain from rigidly defining the parameters of a harmonious environment and encourages the search for mechanisms of mutually harmonious transformation of diverse environmental entities. These principles are bases of the architectural environment harmonization theory. The causes and consequences of actions aimed at improving the environment, which forms and continuously changes as the result of the natural interpenetration anthropogenic, social, and psychological surroundings in the course of their historical development, investigate within this section of architectural theory.

As a result of drawing parallels between the properties of the artificial environment and the ways of thinking of populations' different categories, which were systematized in Socionics [8], sixteen types of architectural environment were distinguished, each of which is presented as an ideal model of living environment for a representative of one of sixteen possible types of energy-information metabolism. The fundamental differences between different types of environmental entities are determining by a unique combination of eight morphological, phenomenological, semantic, and praxeological features that describe their intrinsic and external properties.

The criterion of the architectural environment harmoniousness of each type is the value priority inherent in the carriers of the corresponding kind of energy-information metabolism. The architectural environment harmoniousness criterion of each type is characterizing by a system among eight material, social, humanitarian, and organizational values, indicated in the sequence of reduction of their importance. Each criterion is defining by qualitative and, in some cases, quantitative indicators. As a result, sixteen, fundamentally different descriptions of the perfect environment are forming that characterize the widest possible range of harmony conceptions inherent in persons who have received different ego-orientations, and different sets of psychic functions from birth, according to C. G. Jung's terminology.

From the carriers' point of view of a certain type of energy-information metabolism, the architectural environment looks as a typologically homogeneous void structure with interconnected "mastered" sites. Fragments of urban territory that do not fall within the sphere of vital interests of those persons category form cavities of this structure. From the point of society view, the architectural environment of the city is a mega-structure of sixteen interpenetrating typologically homogeneous layers. Within this megastructure, the "mastered" fragments of each layer put in the voids of all other structures. As a result, in those areas of cities, where the process of forming an architectural environment acquires signs of completeness, environmental systems are forming – combinations of those types of architectural environment that correspond to the value priorities of the members of the respective Dyads, Cuadras, and Octaves, which have been described by Socionics. In this way, favorable conditions created in the urban environment for the territorial-spatial grouping of persons whose social integration is the most productive. With that, fragments of the architectural environment that may interest members of the society, who difficult to find common ground, are physically distant from one another.

The ideal tracery, which would result from the combination of the architectural environment theoretical models, had been comparisoned with the characteristics of real surroundings, which formed at various European cities for quite some time. This comparison showed the ability of the proposed methodology accurately to describe the mechanisms of the natural development of the settlements' architectural environment. Therefore, we can recommend it as an effective means of them harmonization. Application of the proposed methodology application allows identifying sustainable tendencies of environmental systems and environmental networks organization, corresponding to effective forms of interaction between single residents and between individual communities, which have historically formed in different parts of the city. Purposeful support for these trends in the project proposals for the inevitable modernization of settlements will be the key to the harmonious development of the cities' architectural environment and sustainable development of urban communities.

3.3 Sustainable development and architecture of penitentiary facilities

Sustainable urban and community development goals include the provision of universal access to adequate safe and affordable housing and essential services [2]. This requirement also applies to those members of society who deprived of their liberty for one or other reasons.
The concepts of the ideal penitentiary, which is certainly a part of the social, urban and cultural (subcultural) system of the world, known since ancient times, can only be mentioned by Panopticon of Bentham – the "seeing eye" of law and order, the Pennsylvania and progressive 18-19 century, criticism of the modern prison system M. Foucault, etc. Another thing is that the aestheticization of the architectural environment of the correctional system in the context of its improvement and progressive development has hardly attracted the attention of researchers and practitioners until recently. Considering the correctional system from the standpoint of realization of the ideas of the urban environment synergism and harmonization, of which penitentiary complexes are part, we can argue that, to paraphrase F. L. Wright's words, the sign of harmony is inherent for any well-balanced system. However, today, to imagine a prison system that is perfectly balanced, integrated into the urban environment, and therefore harmonious and beautiful in all respects, is quite difficult.

Problems of formation of innovative penitentiary institution, which would combine elements of new and historically traditional in its system, search for variants of harmonious relations between elements of economy, ecology, humanity, and beauty, which is a sign of the system's stability, expressed in search and experimental projects of correctional complexes, history as it is today. Examples of the desire for the aesthetic perfection of the penitentiary environment, which is an integral part of the modern city, can serve almost all the basic prototype models of prisons and correctional buildings, which revealed attempts to combine penitentiary technology of correction and supervision, functional search for aesthetic and artistic relevance emotional orientation of architectural forms. Such attempts at harmonization include the New Gates Prison in London (1770-1785), the Panopticon of J. Bentham (1791), the Philadelphia Prison in Cherry Hill (1825), and the Pentonville Prison in London (1842)) Arnhem Prison in the Netherlands (1884, reconstructed in 1992), and their "followers" – correctional institutions of the "new generation" of the mid-late twentieth and early twentieth centuries.

The principles of improving the penitentiary environment should work at all levels of its system organization and cover the spatial-temporal, functional, structural, planning, and compositional aspects of the harmonization process. Functional harmonization of the penitentiary system ensures optimal flow of the life process, which expressed in accordance with the rhythms and regimes, in the sequence of processes, and corresponding harmonization measures. An example of such relevance and orderliness are the latest-generation "cluster" correctional institutions, in which isolation and combinations of different groups of people and activities occur rhythmically and organically inappropriate spaces, which can act as part of a single mechanism, both as an autonomous and self-sufficient its subdivision [9] (Fig. 1).

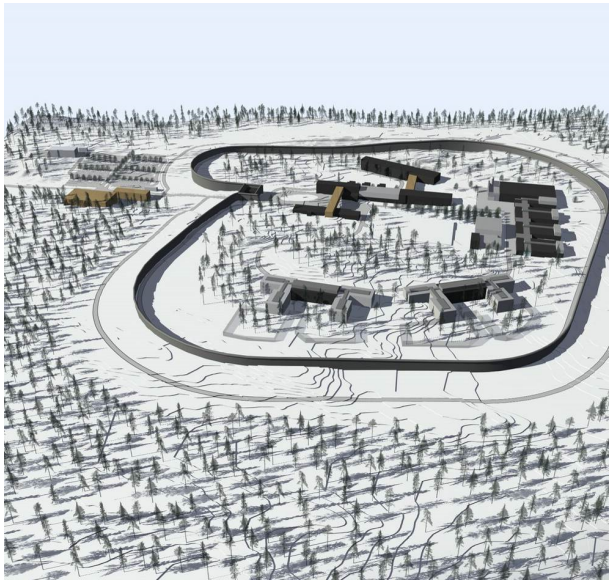

Fig. 1. Halden Correctional Facility, Norway, 2010, https://prisondesign.wordpress.com/2011/05/10/chris-alker-on-the-architecture-of-re-socialization/

The diversity of approaches to the placement of penitentiary complexes in the structure of the city is because environmental actors are not only sentenced and official staff but also residents and visitors. For this reason, at the urban level, the environment of correctional complexes works mainly emotional and psychological indicators that characterize the perception of the penitentiary complex from the outside environment. The harmonious placement of penitentiary complexes in the city implies interactivity between the penitentiary and urban environment in terms of, first, the effectiveness of the penitentiary complex as an element of the social services system, and second, its representativeness, that is, the representative architecture. This approach is in line with the guidelines outlined in the latest guidance documents for achieving sustainable urban development through investment in infrastructure and urban design for climate change and improvement, as well as enhancing social inclusion and accessibility of services for all residents, regardless of age or status, by condition for adherence to the principles of universal design [10].

An important feature of the aesthetic perception of the general appearance of the security institution is the expressiveness and imagery of the silhouette of the complex. Due to the high fence, the perception of the complexes from the far plans made realized by increasing the number of floors in some buildings or by arranging a panoramic view of the architectural ensemble from high points of the landscape, which does not meet the requirements of the regime. Therefore, it is advisable not to increase the number of buildings stories, but to give importance to the architectural and artistic design of the fence and main entrance, similar to the

correctional facility in Bastoey, Norway (Fig. 2), Florida State Correctional Institute in Marianna, US, and more [11]. Techniques for forming a distinctive compositional connection of buildings and structures with the environment – landscape or urban development – contribute to the inclusion of such institutions in the existing system of architectural and urban development, increase the socio-psychological "transparency" of the correctional system and improve the interrelationship.

Fig. 2. Correctional Facility in Bastoey, Norway, https://www.gettyimages.com/photos/bastøy-island

Equally important is the aesthetics and harmonization of correctional buildings and complexes with the environment is the creation of their visual connection with urban development, which carried out by two compositional means: the continuation of the rhythm of development and the creation of emotional and psychological contrast with the urban environment. The first of these can be illustrated by the architecture of the Maryland Correctional Center in Baltimore, USA, which was reconstructed and opened in 1995 [12] (Fig. 3). The new buildings, whose architectural and artistic features correspond to the rhythm, silhouette, and scale of the surrounding urban development, became a visual extension of the old building. Another technique that contrasts the dominant and background volumes is illustrated by the high-rise metropolitan Chicago Metropolitan Correctional Center, designed by G Weiss in 1975 [13], which rises above the surrounding structure and contrasts with its size, tectonics, and dynamics forms (Fig. 4).

Fig. 3. Maryland Correctional Center in Baltimore, https://www.baltimoresun.com/politics/bs-md-pol-city-jail-demo-20191002-prhkw7odwrepvmb4zkt4uxx7ka-story.html

Fig. 4. Metropolitan Correctional Center in Chicago, USA, https://chicagomodern.wordpress.com/2012/03/19/metropolitan-correctional-center/

3.4 The organization of public spaces in areas with dense historical buildings

Today, cities are not only centers of economic and social activity, but also powerful communication hubs, places of trade, culture, science concentration, focuses on innovative development, etc. However, in the context of accelerated globalization in congested cities, problems related to the increase of social inequality, lack of adequate housing and developed infrastructure, environmental degradation, irrational use of energy, accumulation of waste, transport overload, and lack of comfortable public spaces are exacerbating. The situation in the central zones of the largest Ukrainian cities indicates the lack of areas intended for communication, recreation, and leisure. The free urban space used only for pedestrian and transport traffic or is not used at all and transformed into an urban wasteland.

Among the challenges of sustainable urban development, considerable attention pay to ensuring universal access to safe, accessible green areas and public places, open for everybody, especially women and children, the elderly and the disabled [2]. One of the alternative solutions to this problem in the context of dense urban development is the formation of open multi-level multifunctional public spaces able to concentrate a large number of comfortable and interesting facilities for leisure, recreation, interpersonal communication in a relatively small area.

As any other place of public life concentration, multilevel public spaces should be accessible and versatile, create conditions for various activity forms, provide visitors' comfort, make impression of hospitable places, include attraction points, promote socialization, have a sufficient degree of isolation from the unfavorable urban environment [14]. We propose making public spaces pedestrian. For this purpose, to create public transport' stops, tiered parking, and cultural facilities at the outer boundaries' nodes of multilevel city structures.

This scheme designed for use in historic downtown and near particular value architectural complexes. The system of public spaces historically formed in such places gets territorial development through the modernization of certain sections of existing streets, squares, embankments, esplanades, as well as through the development of underground or aboveground levels through the degraded urban landscapes regeneration, in particular industrial facilities. Territorial reserves for the organization of multi-level public spaces also can found in the green areas of cities. Parks and squares, sections of boulevards, and embankments can combine into single spatial systems by arranging additional multi-level links of well-established walking routes.

The live plants that integrated into multi-tiered urban structures, design to organize public spaces [15], will increase the number of green spaces in densely built historic city centers. This path may be one of the most promising means of improving the microclimate in the urban environment.

Creating new urban public multi-level centers in the business, cultural, and shopping regions will help to promote the new technologies introduction, and unique architectural concepts implementation [16]. At the same time, traditional types of urban environments such as a square, a boulevard, a park or a trestle, can get a new interpretation here.

Maintaining the historical architectural ensembles unity and the modern constructions are key importance in the process of reorganizing existing open public spaces or creating new public life centers in multi-tiered urban structures. The constructive system of the objects introduced into the formed urban environment is an important element that influences their three-dimensional solution. For the erection of multilevel urban structures, we propose to use beam, beam-cantilever, arch, frame, and combined structural schemes. The structural scheme of a multi-tiered urban structure can transform it into a visual dominant for the entire city area [17] (Fig. 5) or facilitate its maximum integration into the existing architectural environment [18] (Fig. 6).

Fig. 5. Metropol Parasol. Seville, Spain, http://www.twofeet-oneworld.com/2017-12-two-days-seville/dsc00843/

Fig. 6. La Défense Business District. Paris, France, http://grandstroy.blogspot.com/2012/11/grande-arche-de-la-defense.html

New effective materials, including recycled materials, designed to reduce the cost of multi-tiered urban structures, accelerate their erection process, reduce operating costs, and indirectly improve the environmental status of cities as a whole. For example, various products - from insulation materials and exterior facades decoration to individual elements of public spaces [19] (Fig. 7) and urban furniture [20] (Fig. 8) can made from polymer-sand composite materials or recycled plastic.

Fig. 7. Pavement tile made of polymer-sand composite, http://newslab.ru/article/719194

Fig. 8. Recycled plastic bench, Amsterdam, Netherlands, The New Raw, https://thenewraw.org/Print-Your-City-Amsterdam

The organization of multifunctional multilevel public spaces will facilitate the sustainable development of cities if they will thoughtfully embedded in the existing context. This process requires the development of a long-term action program that, based on the available opportunities analysis, will justify the feasibility of reorganizing the architectural environment as a means of harmonizing the living environment of urban communities and ensuring settlements balanced development.

3.5 Implementation of advanced resource reuse technologies

An equally important challenge of modern time is to reduce the negative environmental impact of cities by improving air quality and reducing the amount of waste per resident [2]. The overall state of the environment continues to deteriorate despite the introduction of environmental protection and conservation measures [21]. The concentration degree of harmful substances in the atmosphere exceeds the established norms in some Ukrainian cities [22]. Currently, there are waste recycling enterprises in Ukraine, including plastics, such as “Kyivmiskvtorresources”, “Region-2001” and “GALPET”, whose products are mainly relatively inexpensive raw materials – granular PET, preforms, PET flakes [23]. Waste collection and sorting are expensive, and the sales revenues are insufficient for further develop production facilities in accordance with current technologies. Due to this and to insufficient support from the state, the garbage processing service at some Ukrainian enterprises as “Region-2001” is pay [24], and some as “Kyivmiskvtorresources” have to stop their activity altogether [25].

Instead, society is interested in changing approaches to waste management. There is a need to develop effective recycling methods to avoid incineration and disposal procedures. The use of secondary raw materials in construction is one such way. A distinctive feature of this method of using recycled materials is its economic benefits since construction products made from recycling expected to be significantly cheaper than similar ones made of prime raw materials.

There are household waste, industrial waste, construction, and repair waste to use in architecture. We chose polymer waste for research, because it pollutes the ocean more than others do, and its processing has great potential. The use in the construction of polymeric recyclables meets the needs of sustainable urban development due to the relatively low cost of energy resources due to the low melting point of plastics. Due to the plasticity of the material and its suitability for painting, construction products based on polymeric recyclables have a high potential for increasing aesthetically attractive architectural and construction products.

Secondary raw materials can act as a constituent of building material or be the only component for the manufacture of construction products. There is some experience with the introduction of both technologies: for example, in India, recycled plastic is using as a filler in concrete instead of sand [26], and in the US, recycled plastics are using as a base material for building blocks [27].

An important disadvantage of existing the production of construction products based on secondary raw materials is its aesthetic and, in a way, psychological unattractiveness. Despite the economic and technical benefits of using such building materials, likely not all potential users will want to transfer their activities to an environment created from recycled waste. Therefore, an important task is to determine the acceptable scope of application of the material based on recycling and to develop solutions designed to improve the aesthetic qualities of such products.

These materials can used in the mass industrial production of prefabricated architectural elements and decoration materials, mainly for non-residential construction. Exactly physicomechanical properties allow used them forbearing and self-bearing structures of low-rise buildings and structures. The recyclable materials have good performance characteristics, low thermal conductivity. They are safe with the addition of flame-retardants, stabilizers, and non-combustible binders such as concrete. Therefore, it is reasonable to use them for the production of bearing structures of any type of buildings and structures or as finishing materials [28, 29] (Fig. 9, 10).

Fig. 9. Residential complex in Copenhagen, Denmark, by Lendager Group, https://www.dezeen.com/2019/04/16/upcycle-studios-townhouses-lendager-group-copenhagen-recycled-materials/

Fig. 10. The school in Colombia, http://conceptosplasticos.com/

Recycled materials constructions are high durability, resistance to chipping, and low-cost. Therefore, we can use them in detention facilities to resist walls deformation for prevention prisoners from escaping. Sustainable and diverse materials based on recycling materials can be a major component in the industrial production of low-cost pavement elements, as well as aesthetically appealing elements of improvement (Fig. 11).

Fig. 11. Capacity for the plant, http://conceptosplasticos.com/

It is likely that in the further development of recycling technologies for polymeric materials will make it possible to manufacture a wide range of available construction products that will have high physical and mechanical qualities and a variety of aesthetic properties. The use of such architectural and construction products will expand the arsenal of the humanization of the urban environment. For example, new public spaces in densely populated central areas of coastal historic cities and mobile, environmentally neutral visitor facilities in pristine natural landscapes can produce from floating modules from recycled materials [30]. In this way, the introduction of advanced resource recycling technologies will help to strengthen overall sustainable development trends.

4 Conclusions

The ideas of sustainable development, which has a long history, has always attracted the attention of architects and urbanists from the standpoint of creating a perfective architectural environment in cities and urban areas. Today, the formation of a full-fledged environment increasingly focused on its harmonization, which aimed at overcoming the existing urban chaos and maximizing the use of internal reserves and the potentials of an effective organization and self-organization of the urban environment at all levels, stages, and locations of its development. The study shows that the harmonization of urban planning, as a whole, its specific spatial and functional components, as well as individual types of buildings, despite their complex multi-vector nature, together constitute not yet fully realized potentials and reserves of sustainable.

Ways to improve the architectural environment are associated with the implementation of synergistic methods in the practice of urban planning. In cities, it is advisable to purposefully formulate systems of the architectural environment that correspond to people with different psychological characteristics. Ways to improve the architectural environment must also be associated with the enhancement of aesthetic qualities of penitentiary buildings and their thoughtful placement on the territory of the settlements, with the creation of multifunctional multilevel public spaces and with the expansion of the reuse of industrial products and materials. The humanistic focus of harmonization allows reconciles the goals and values of free urban communities and groups with temporarily restricted freedom. It contributes to forming the full-fledged architectural environment of cities with the attraction of new concepts and ideas for sustainable development, as well as innovative technologies of architectural and urban planning, taking into account the aesthetic preferences and artistic tastes of urban residents and their communities.

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About new aspects of the development of the market of mini apartments in Ukraine

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Abstract. The article discusses the issues of a new segment of the real estate market in urban development projects. The analysis of the world market of mini apartments is made. The questions of residence of various social groups in mini apartments are raised. The classification of mini apartments has been developed. The factors significantly affecting the cost of a mini apartment are investigated. The calculation of the analysis of benefits and costs for a mini apartment. Conclusions are drawn about the mini-apartment market in urban development. The research of mini-apartments' market reflects changes in the development of the whole urban infrastructure. The market of mini-apartments influences on the real estate region's market. The distinctive characteristics of mini-apartments in different regions are based on their classification. The mini-apartments' market in different regions is analyzed. The authors constructed GIS-map. GIS analysis shows the dependence of the cost of mini apartments from the region of Ukraine. Calculation of the profitability of mini apartments was carried out using the method of market extraction (market sampling). Using the method of market extraction (market sampling), the income from mini apartments was calculated. Cost benefit analysis shows the aspects of the mini apartments' market for the urban development.

1 Introduction

The first time mini-apartments – studios appeared as a budget housing was in the 1920s in the US. They were in a high demand among the poorest groups of the population. The accommodation had open space and separate bathroom. It became convenient for the students, single and creative people. It was an excellent solution to the housing problem [1, 2]. At the present time studio apartments have become popular all over the world.

A studio apartment, also known as a studio flat is a small apartment which combines living room, bedroom, and kitchen into one room.

In Italy such objects are called "monolocale". In Japan such objects which are studio apartments known are called the one room mansion. In United States (New York) is the "L-shaped" or "alcove" studio. In Canada – "bachelor" apartment. In Czech Republic – Garsoniéra. In Poland studio apartments are called "Kawalerka". In United Kingdom such objects are called studio flats [15].

We have done an analysis of the value of real estate in different countries of Europe. We took the statistics of the average cost of 1 m^2 apartments with an area of about 120 m^2 located in major cities of Europe as of August 2019. Dynamic of residential property can be seen on Figure 1.

The residential property market in Europe shows signs of recovery, one of the main characteristics is the price increase. After the financial crisis, many European real estate markets became more active and the prices started to rise.

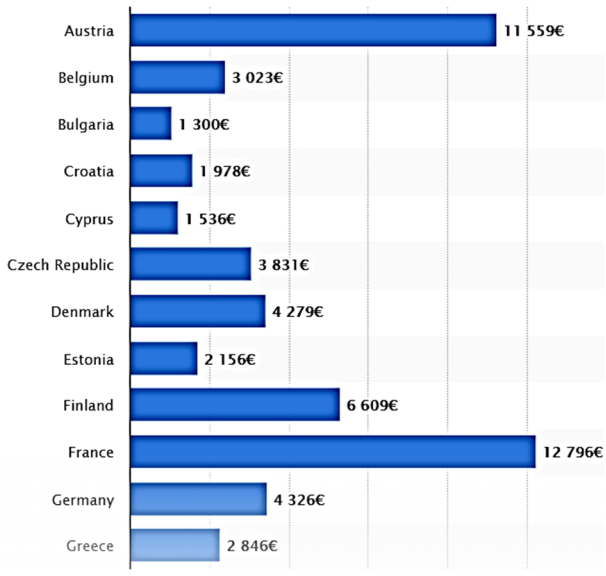

Fig. 1. Average price of residential property in EU-12 according to the statistics [14].

Average prices of 120 square meter apartments located in the most important cities of EU-12 countries were highest in the United Kingdom, France and Austria as of August 2019. These cities could either be the administrative capital, the financial capital and the center of the rental market.

Newly built and pre-sale property prices were not included. An apartment located in the United Kingdom most important city would therefore cost approximately

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21,179 euros per square meter. The source does not specify the cities and states that the numbers provided in this ranking have been taken from several national publications, for example from national statistical bureaus. This is because no European level body exists that tracks house prices. As of July 2018, the average price for a house in the UK was 231,163 British pounds.

With this development of the real estate market, it is necessary to analyze the activity of the mini-apartment market. Studies have shown that the cost per square meter of a standard apartment is approximately equal to the cost per square meter in a mini apartment. The rent for a mini apartment is higher.

In Ukraine "gostinka" is a mini apartment in an apartment building with its own mini-bathroom and mini-kitchen. This is a small room without walls or partitions, mostly adapted for 1-2 people and a total area of 25 m^2. In fact, this is a new kind of social housing.

2 The development of the market of mini apartments in Ukraine

The development of the market of mini apartments can be regarded as a new social phenomenon. Many social groups can afford them to buy a mini apartment.

The real estate market is at a difficult stage now [15-18]. The economic crisis had a strong impact on stakeholders [4, 16]:

1. Developers are forced to reduce the cost of housing.
2. Customers have less money to buy.

The reconstruction of the old houses, factories, unfinished buildings began. In Kharkiv, one of the major cities in Ukraine, all these buildings were reconstructed as a special house with mini apartments. This direction is developing rapidly today. Houses with mini apartments exist practically in all parts of the city. In urban planning, it is necessary to consider the development of this market segment and its impact on various social groups of the population [3, 15, 20]. For example, developers in Kharkiv are building the following residential complexes with mini apartments: "Vorob`yovi Gori", "Alekseevskiy Akvarali", "Bestuzhevsky Sadi", "Uytniy Dvorik", "Eloviy Dvor", "Caramel" and other medium and small projects.

There are more than 30 kinds of such constructions in Kharkiv now.

The market of mini apartments in Ukraine is a very interesting social phenomenon that has not been explored yet. The market of mini apartments influences on the urban development, but it has high uncertainty in further development. Therefore, the development of the mini apartment market poses many challenges for urban development in the future.

Mini apartments are now actively purchased by the following social groups of people:

1. Lonely, independent young people.
2. Young families.
3. Pensioners.
4. Creative people, usually they use it as a separate workspace (workshops, photo studios, small offices, etc.).
5. Investors for rent and income generation.

The activity in Ukrainian real estate market in such segment as mini apartments has increased currently. The results of the conducted studies show that the interval of cost is 1 m^2 for such objects is very large and ranges from $300 to $1000. This is 2 times lower than the average market prices for standard apartments.

Let's analyze the interaction of the primary and secondary markets of mini apartments. Residential complexes with mini apartments can be characterized as:

– new – building and in a new location;
– reconstructed from the former hostels – internal reconstruction;
– reconstructed from commercial buildings, for example, former buildings of the plant management (internal reconstruction);
– reconstruction with superstructure of floors;
– reconstruction with the addition of premises (as a rule, large areas).

Stakeholders are interested in mini apartments in reconstructed houses. In these houses, the cost of mini apartments is much lower. And mini apartments are sold at the lowest market value.

We propose a classification of mini apartments:

By location:

1. Remote zones – factory buildings.
2. Remote zones – residential development.
3. Middle areas in non-residential buildings.
4. Middle areas in residential development.
5. Zones close to the center and center in non-residential buildings.
6. Zones close to the center and the center in the residential building.

By living area:

1. Large rooms over 20 m^2.
2. The average size of 10 to 20 m^2.
3. Smaller than 10 m^2.

By the presence or absence of a bathroom and a mini kitchen:

1. Own bathroom, mini kitchen is separated from the bedroom.
2. Own bathroom, mini kitchen is in the room (studio).
3. Own bathroom, no mini kitchen.
4. A common bathroom, a common mini kitchen.

The Kyiv International Institute of Sociology and the Institute for Economic Research and Political Consultations of Ukraine conducted research and determined the investment attractiveness rating of the regions of Ukraine [7-9]. Rating of investment attractiveness and average cost of 1 m^2 of mini apartments in Table 1.

We processed and analyzed the data in Table 1 and built a GIS map. The GIS map shows the distribution of the cost of 1 m^2 mini apartments in large Ukrainian cities on Figure 2.

Based on GIS analysis, we can conclude that the cost of 1 m^2 of mini apartments depends on the investment attractiveness of the regional center in Ukraine [9, 13]. This information confirms the presence of a multifactor component and the investor's interest depends not only on the buyer's demand for the acquisition of real estate in the city [20-22]. It is necessary to pay attention to the stability

and a rating indicator on investment rating of a city [10-12], [16].

We classified mini apartments according to factors that can significantly change the market value [21, 22]. These factors can increase or decrease the market value of real estate [2]. Such a parameter as the ratio of total and living space can also significantly change the market value for a mini apartment.

As a result of the research, the author suggests factors affecting the market value for a mini apartment.

1. Location (distance from transport and public infrastructure).
2. Floor.
3. Material of walls and ceilings.
4. The general plan of a mini apartment.
5. Design features of a mini apartment (shape and size of the room).
6. The availability and size of the toilet.
7. The availability and size of the kitchen.
8. The availability of a balcony.
9. General condition of entrances, common corridors and adjacent territory.
10. The availability of autonomous heating and the total cost of utility payments.
11. The number of rooms and neighbors on the floor and in the entrance.
12. The general level of the social groups, which is showing their standard of living.

Table 1: Investment rating and average cost of 1 m^2 of mini apartments for large cities in Ukraine.

City	Cost of mini apartment for 1 m^2, $	Investment rating, $
Lviv	946	3,662
Ivano-Frankivsk	401	3,381
Odessa	916	3,337
Vinnitsa	446	3,266
Kyiv	1070	3,246
Dnipro	591	3,243
Lutsk	448	3,225
Kharkiv	696	3,211
Chernigov	-	3,195
Zhitomir	453	3,168
Ternopil	-	3,102
Zaporozhye	443	3,099
Rovno	-	3,072
Sumy	378	3,063
Mykolaiv	-	3,040
Cherkassy	-	2,996
Khmelnytskyi	416	2,948
Poltava	457	2,935
Kirovohrad	400	2,935
Uzhhorod	-	2,914
Kherson	-	2,891
Chernivtsi	-	2,859

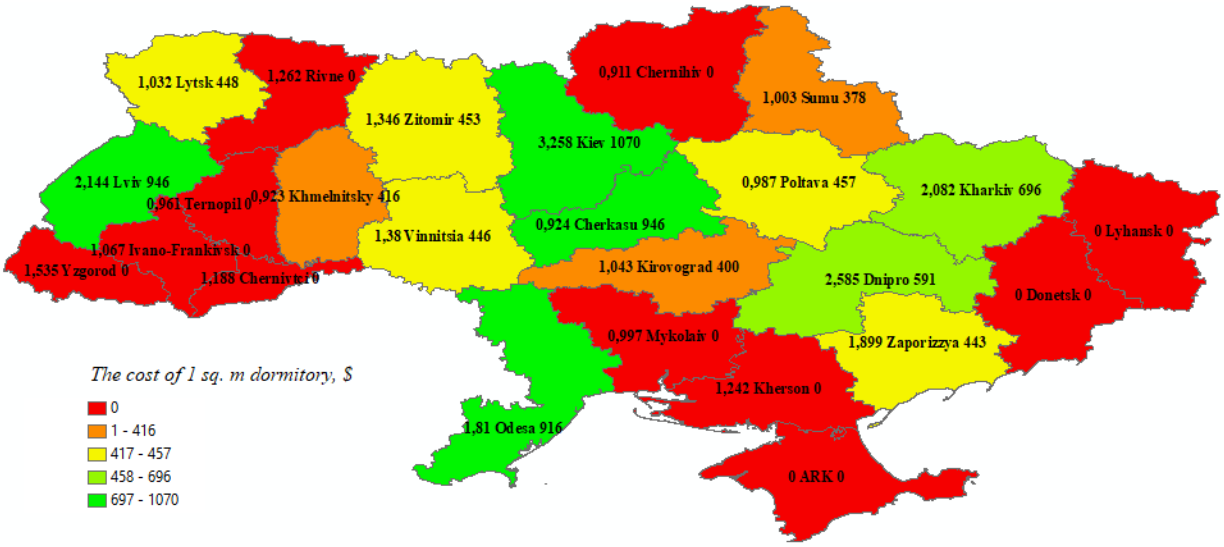

Fig. 2. GIS map of the distribution of the cost of 1 m^2 of mini apartments in Ukrainian cities.

In Ukraine, the market of mini apartments (Gostinka) has formed and developed because of the unstable economic situation, devaluation of UAH and a decrease in the incomes of the population. Today, renting apartments is expensive, so mini apartments are the best option for affordable housing. Many people buy mini apartments as a temporary housing. This segment of real estate has a high profitability for investors. The cost of 1 m^2 of mini apartments depends on investment rating of large cities in Ukraine.

3 The market research in Kyiv and Kharkiv

In many large cities of Ukraine, especially in Kyiv and Kharkiv, the number of mini apartments, being under construction is growing. The analysis showed the market that such apartments are in demand among stakeholders today [17, 18].

Factors of increasing the demand for mini apartments:
– an unstable economic situation;
– reduction of money supply in the population;

– distrust of the banking sector;
– large bills for the use of real estate;
– high payments for real estate with a large area;
– increased functionality;
– comfortable for 1-2 people.

In Kyiv, there are about 10 new housing complexes with mini apartments. For example, there are such housing complexes as: “Smart House”, “Comfort Town”, “Yaskravy”, “At Levadnaya”, “Vlasna Apartment”, “Zhuliany”, “Yeniseiskaya Usadba”, “Henesi House”, “New England”.

The minimum price for a mini-apartment in Kharkiv varies from 6,000 $, in Kyiv – from 10,000 $.

The market value of a mini apartment grows from the beginning to the finishing of the building at 2-4 thousand dollars more. This is about 20-30% of the market value [5].

In Kharkiv, mini apartments in new houses are sold without renovation. In Kyiv – with full renovation, often with equipment. A feature of the Kharkiv market is that there are two-level mini-apartments (smart-apartments). In Kyiv, there are none. Studies of the rental market show that there are 78 mini apartments in Kharkiv for rent. In Kyiv 32 mini apartments exposed for a long period of time. A mini apartment rent in Kyiv costs 3,500-8,500 UAH per month, in Kharkiv – 2,000 – 5,000 UAH per month. Daily rent of mini apartments in Kharkiv is more than in Kyiv. Nowadays there are 16 daily rentals in Kharkiv, while in Kyiv there are only 5 [18].

Thus, we can conclude that the market of mini apartments in Kharkiv is more developed than in Kyiv. In Kharkiv, people buy more mini apartments units for the purpose of further renting it out than in Kyiv. The entire market of mini apartments (gostinka) in Ukraine is actively developing.

4 The calculation of income received from mini apartments. Cost benefit analysis

Mini apartment is the most profitable object for investment. This is the best segment of real estate with minimal investment and maximum income on the invested capital.

We will analyze the benefits and value [17] for a mini apartment. We calculate the net operating income for – mini apartment in a residential area of Kharkiv in Table 2.

Table 2. Information about the mini apartment for rent.

Apartment	Characteristics	Income per month
Mini apartment	“Rent an excellent gostinka, 4/5, a new shower cubicle, plumbing, built-in. kitchen, area 20 m^2, 7800 $”	4000 UAH / month

An example of calculating the income from a mini apartment in Table 3.

We apply the method of market extraction (market sampling) [23], to cost benefit analysis. Using this method, we calculate the capitalization rate (R).

Table 3. An example of calculating the income from a mini apartment.

Name	Value, UAH
1. Potential gross income (PGI)	4000
2. Annual PGI	48000
3. Losses (5% from PGI)	2400
4. Real gross income (per year)	45600
5. Operating expenses, including:	15000
- communal payments	6000
- maintenance	2000
- payment for management company services	4800
- advertising	700
- accounting services	1000
- real estate taxes (land tax, property tax)	500
6. Net operating income (NOI)	30600

The calculation results are tabulated and are given in Table 4.

Table 4. Calculation of the capitalization rate and payback time.

Object	V, UAH	NOI, UAH	R=NOI/Vx100%	Payback time (1/R), year
1	210600	28700	1,4	7,1
2	300000	50000	1,7	5,9
3	250000	40000	1,6	6,25
4	330000	48000	1,5	6,7
5	275000	35000	1,3	7,7
			Average R = 1,5	

The capitalization rate is calculated as the ratio of net operating income (NOI) to market value (V) and is based on market information about similar real estate properties [17].

Today it is very profitable to invest in a mini apartment and rent out. The capitalization rate (the rate of return of capital) will be 15%. However, the payback period for such facilities will be from 6 years to 8 years.

5 The prospects of urban development of the mini apartment market

In the real estate market of Kharkiv, in the segment of mini apartments, there are many categories of such apartments [5]. The cost of mini apartment on Figure 3.

In order to sell mini apartments when the real estate market is in the low activity, owners use marketing levers to stimulate demand:
– provide payment by installments;
– make a discount for repairs;
– carry out various kinds of actions (for example, furniture as a gift).

It should be noted that some similar objects are not sold for a very long time.

The cheapest mini apartments according to 01/04/2018 are for sale in the KhTZ area – from 4,000 $. The average offer price of one-room mini apartments with its own bathroom is 8,000 $, with a shared bathroom 6,000 $. The average range of the cost of mini apartments ranges from 3,000 $ to 16,000$ [16].

Mini apartments in the reconstructed houses can be

bought from 8,000$ to 17,000$ (400 – 700 $/m^2 an area of 10 – 36 m^2). Buying redecorated mini apartment will cost 1000 $/m^2.

Thus, we can conclude that the range of value of 1 square meter in this segment of real estate varies very much. From 300 $ to 700 $ and even reaches up to 1,000 $/m^2. The rental market for mini apartments has a range of 90 – 198 $ on Figure 4.

The market of mini apartments is the most promising for investments in the structure of city development [18].

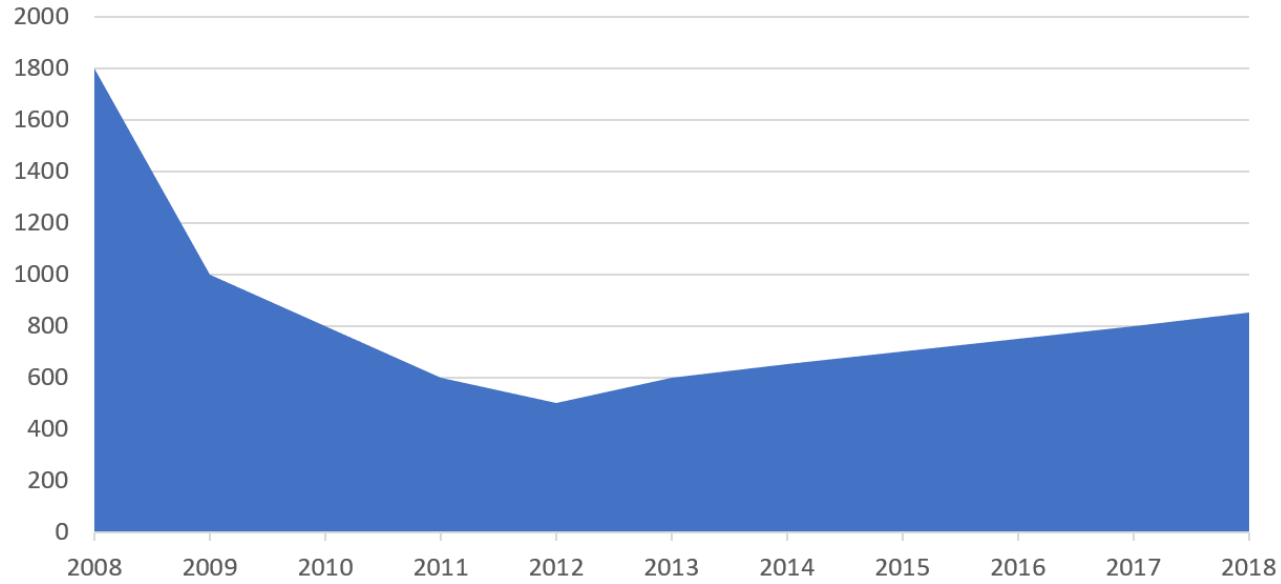

Fig. 3. The cost of mini apartments from 2008 to 2018 [17].

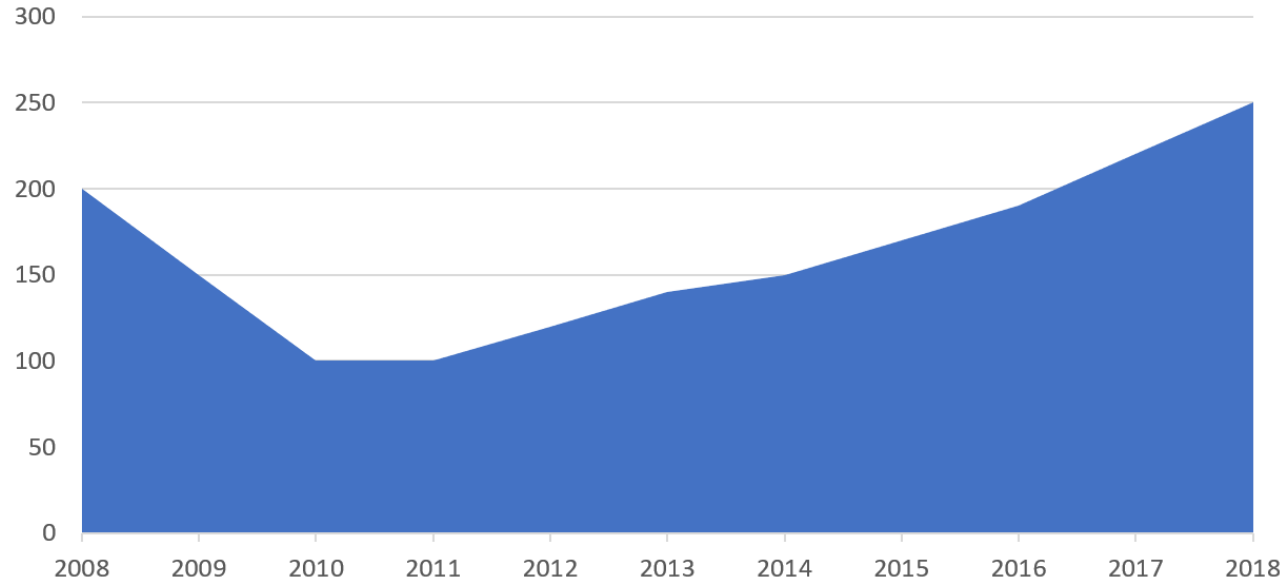

Fig. 4. The average price of renting a mini apartment in Kharkiv, [17].

6 Conclusions

1. The development of the mini-apartment market can be regarded as a new social phenomenon in the large cities of Ukraine. The decision on the issue of a new segment of the real estate market in urban development projects is highly relevant.
2. In Ukraine, the market of mini apartments has emerged and is developing because of the unstable economic situation, the devaluation of the hryvnia and the decrease in the incomes of the population. The cost of 1 square meter of mini apartments depends on the investment attractiveness of the regional center.
3. In Kharkiv, customers buy more mini apartments for the purpose of further rental than in Kyiv. The entire market of mini apartments in the large cities of Ukraine is actively developing.
4. The range of cost of 1 m^2 in this segment of real estate varies from 300 $ to 1,000 $. The rental market for mini apartments has a range of 77 – 193 $ for a mini apartment.
5. Today, it is very beneficial to invest in a mini apartment and renting out. The capitalization rate (the rate of return of capital) will be 15%. The payback period for such an object will be from 6 years to 8 years.

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Modeling of complex diversification for centralized pharmacy network

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Abstract. The risk management of a centralized pharmacy network identifies the research object. The paper proposes a strategy of complex diversification for the pharmacy network. By constructing portfolio models for complex diversification and solving relevant multicriteria problems, multiple pareto-optimal portfolios have been found for successive risk management. Based on the fundamentals of Markowitz portfolio theory and multicriteria optimization, this paper builds four models of the optimal portfolios for centralized pharmacy network. In contrast to the classic two-criteria model (risk minimization while maximizing income), our models have been introduced to maximize entropy, which enhances the diversification effect. Matlab software has been developed for solving multicriteria problems. Model verification was performed on real data provided by one of the pharmacy networks. The modeling results will be useful for automating the business processes of any trading network, managing risk, analysing loyalty programs to improve the effectiveness of their operations.

1 Introduction

The modern pharmacy market of Ukraine is characterized by a fierce competition between its leaders. The consolidation of pharmacy networks is continuing actively. For 2017-2018, the share of TOP-100 pharmacy networks by sales increased by 8.4%. All this is against the background of market sales growth of 15% (up to UAH 40.6 billion in the first half of 2019) in UAH terms and a decrease of 3% in kind (up to 543.7 million packages) [1].

The decrease in demand is a reflection of the fact that the pharmacy market is subject to fluctuations, since it is almost entirely financed by the consumer and directly depends on the well-being of the population. This indicates the risks involved in managing the pharmacy network. And ignoring these risks will lead to a loss of profit, loss of financial revenues, and a decrease in the level of competitiveness of the network. For sustainable development and dynamic growth, pharmacy networks need to diversify their operations by optimally allocating their own resources across outlets. This will avoid the large group of risks associated with the likely occurrence of losses in the sale of products or services. Risk tracking allows the network to respond to internal and external changes in a timely manner, reducing financial, material, moral, human and other losses.

A pharmacy network is an amalgamation of pharmacies whose consolidation is based on certain principles. There are pharmacy networks of three types: holding; centralized; mixed [2].

Holding type pharmacy network is a collection of pharmacies and subdivisions, each of which has its own Code of the Unified State Register of Enterprises and Organizations of Ukraine. They can have their own bank accounts, act independently, but have one owner, that is, they are only formally linked.

A centralized pharmacy network is characterized by the fact that all pharmacies and units have a single Code of the Unified State Register of Enterprises and Organizations of Ukraine, and a license is generally allowed under the same license; pharmacy banks do not have their own accounts.

A mixed-type pharmacy network is a structure in which the characteristics of holding networks are combined with those of centralized ones.

The conducted studies are based on the basic principles of the classical portfolio theory of Markowitz [3], of Contemporary Applications of Markowitz Technique of J. B. Guerard [4], the modern digital portfolio theory K. Kenneth Jones [5], The works of the Ukrainian scientist B. Yu. Kishakevich [6] are known in the field of multicriteria modeling of optimal loan portfolios. However, despite numerous results, the problem of modeling the comprehensive diversification of the pharmacy network has not been previously investigated.

The attempt of the state to directly influence the pharmacy market resulted in the Draft Law "On Amendments to the Law of Ukraine" On Medicines "on Ensuring Economic Competition and Protecting Patients' Rights in Retailing of Medicines" No. 8591 of 12.07.2018.

The bill establishes significant restrictions on opening pharmacies by establishing a distance between pharmacies of at least 500 meters; the number of

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pharmacies in legal entities – no more than 8 pharmacies within one area, and individuals – entrepreneurs – no more than 1 pharmacy; introduction of unequal conditions of activity of municipal, state and private pharmacies. However, it should be noted that the pharmacy network – the market leader occupies just over 11% of its volume among legal entities, the top 3 hold 23.6%, the top 5–30% of the market. The top 100 drugstore networks accumulate 73% of the pharmacy market. Single pharmacies and pharmacy networks, which have up to 10 pharmacies, own 46% of the outlets. Megamans (more than 50 outlets) generally own 36%. All this indicates that the pharmacy market is not monopolized with a large number of players on it, and therefore there are risks to the network in a competitive environment.

The object of the study in this paper is to manage risks in the functioning of a centralized pharmacy network by diversifying the portfolios of its structural elements and the network itself as a whole.

The purpose of the work is to build a complex of models of diversified portfolios and to study them under different operating conditions, which in particular are caused by changes in the legislation and the rapid development of the information society. The emergence of such processes in Ukraine is the emergence of a National Electronic Health System in Ukraine "eHealth" [7].

2 Optimal portfolio models of pharmacy network

Research on the functioning of the pharmacy network as a whole based on a systematic approach raises the question of determining the overall structure of the system that would provide optimal modes of functioning and adaptation. A pharmacy network is considered to be an open system consisting of several interconnected subsystems; combines goals, resources and processes that occur within and around the network.

For the pharmaceutical supply system, the characteristic features are the hierarchy of control systems, the presence of elements of different origin and functional orientation, a considerable number of subsystems.

Diversification represents a strategic decision on the possibilities of enterprise development by managing the portfolio of different types of activities of the units or taking advantage of the competitive advantages of joining efforts to achieve a single goal; expansion of directions of activity of the enterprise. Diversification is a tool for adapting the pharmacy network to achieve the strategic goals of the company, such as reducing risk, enhancing the financial stability of the network, stabilizing financial revenues, building the potential for competitiveness and insensitivity to market changes. Increasing the financial stability of the network is due to the increase in the value of working capital by obtaining the maximum financial result from the purchased goods in the least period of time [4].

The diversification process is complicated by the fact that the pharmacy network is a structure that does not have its own production base, resells the available goods and does not have the ability to influence their price and quality characteristics, but can optimally select the assortment according to the specific needs of each outlet. In addition, the pharmacy network operates in a highly competitive market, which limits its agility in the process of forming the final price of the product.

A qualitative approach to managing the pharmacy network outlets in a highly competitive marketplace minimizes the risks of the actual or potential decline in the profitability of pharmacies.

Applying a portfolio approach in this paper, we examine the complex process of pharmacy network diversification, taking into account the activities of suppliers, the network itself and customers over a single period of time.

Flowchart of a complex diversification program is presented in Figure 1.

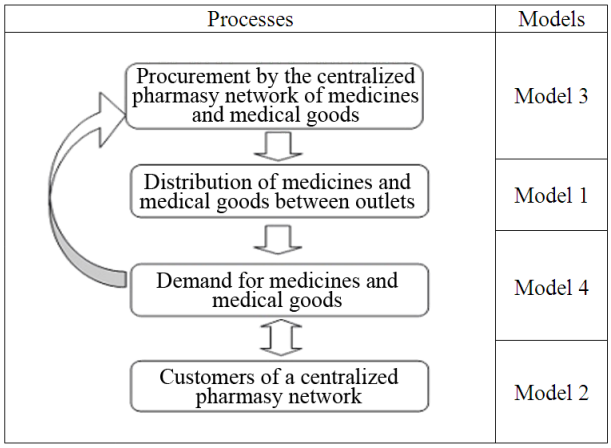

Fig. 1. Flowchart of a comprehensive diversification program.

All models have the same composition of the vector objective function, which consists of three criteria: Risk, which is reduced; Sum is the portfolio yield that is desirable to increase; Entropy as a value that characterizes the level of diversification of the relevant portfolio (diversity assessment) that the pharmacy network is trying to increase in its activities. In addition, each model has its own specific system of constraints, which is determined by the business process of the pharmacy network in the structure of its activities.

2.1 Portfolio model of optimizing the distribution of finances

Let's build a formalized portfolio model of optimizing the distribution of finances between outlets of a centralized pharmacy network – Model 1. By distributing goods optimally across outlets, the network earns maximum profits by responding promptly to the circulation of drugs over a period of time, since demand for drugs in a particular pharmacy is not constant and goods that are not sold in one outlet can be timely sold in another and generate profits without increasing the length of the composition. Trade turnover of a pharmacy network is the

sum of trade turnover of its pharmacy establishments. The turnover of an individual pharmacy is estimated to be sufficient at the level of UAH 2 million, which defines additional limitations in Model 1.

Let x_i is the share of the *i*-th pharmacy in the turnover of the pharmacy network, which is equal to the share of allocated financial resources in the *i*-th pharmacy; a_i – expected turnover of this pharmacy (UAH); *n* is the number of pharmacies in the network.

In this model, the Risk criterion – structural risk – is the risk of irrational distribution of financial resources of a centralized pharmacy network between outlets. Structural risk is defined as the covariance of turnover of *i*-th and *j*-th pharmacies.

So, we have a multicriteria quadratic programming problem.

$$\begin{cases} Risk = \sum_{i=1}^{n}(a_i - \bar{a}) \cdot \left(a_j - \bar{a}\right) \cdot x_i \cdot x_j \to min, \\ Sum = \sum_{i=1}^{n} a_i \cdot x_i \to max, \\ Entropy = -\sum_{i=1}^{n\Sigma} x_i \, ln(x_i) \to max, \\ \sum_{i=1}^{n} a_i \cdot x_i \geq 2 \cdot 10^6 \cdot n, \\ \sum_{i=1}^{n} x_i = 1, x \in [0..1]. \{ \end{cases} \quad (1)$$

The solution to problem (1) is the vector $\overline{X^*} = (x_1, x_2, \dots, x_n)$ – the optimal plan for the distribution of financial resources of the central pharmacy network between outlets.

2.2 Portfolio model of optimal combination customers

Any medicinal product or medical device has certain properties that are attractive to a particular segment of consumers. The more pharmacy consumers are, the lower the risk of loss of income. We will divide pharmacy customers into three groups: loyal (regular), casual and online clients. We believe that all three customer groups do not intersect. Loyal customers include pharmacy turnover and discount cards. Casual – all other visitors, with low purchase frequency.

The pharmacy network's goal is to increase the average check and purchase frequency for each customer group. To formalize Model 2, we introduce the following notation:

y_1 – share of loyal customers in the pharmacy customer portfolio,

y_2 – share of casual pharmacy network customers,

y_3 – share of online pharmacy customers,

b_i – average check for the *i*-th group of pharmacy network clients (UAH),

$\bar{b_i}$ – expected average check for the *i*-th group of pharmacy network clients (UAH),

q_i – the average frequency of visits to the *i*-th pharmacy customer group,

$\bar{q_i}$ – expected average frequency of visits to the *i*-th pharmacy customer group.

The risks in this situation are the failure to obtain an average check from loyal Risk1 customers and a decrease in the frequency of visits to casual Risk2 clients. This model also provides two criteria that meet the goal of maximizing profitability: Sum1 – the total average frequency of visits to pharmacy customers and Sum2 – the total average check across the network as a whole.

$$\begin{cases} Risk1 = \sum_{i=1}^{3}\sum_{j=1}^{3} y_i \cdot y_j \cdot (q_i - \bar{q}_i) \cdot \left(q_j - \bar{q}_j\right) \to min, \\ Risk2 = \sum_{i=1}^{3}\sum_{j=1}^{3} y_i \cdot y_j \cdot \left(b_i - \bar{b}_i\right) \cdot \left(b_j - \bar{b}_j\right) \to min, \\ Sum1 = \sum_{i=1}^{3\Sigma} y_i \cdot q_i \to max, \\ Sum2 = \sum_{i=1}^{3\Sigma} y_i \cdot b_i \to max, \\ Entropy = -\sum_{i=1}^{3\Sigma} y_i \cdot ln(y_i) \to max \\ \sum_{i=1}^{3} y_i = 1, y_i \in [0; 1]. \{ \end{cases} \quad (2)$$

For problem (2), modifications generated by different combinations of Risk1, Risk2, and Sum1, Sum2 criteria are possible to investigate the effectiveness or development of new loyalty programs. Another modification of the model is to deepen the study of clients' portfolio to the level of each individual outlet. Then the sum of the optimal customer portfolios of a particular outlet forms the optimal portfolio of pharmacy network clients as a whole.

The solution to problem (2) is the vector $\overline{Y^*} = (y_1, y_2, \dots, y_n)$ – the optimal combination of distribution of groups of loyal, casual and Internet clients.

For the task, possible modifications are generated by various combinations of the Risk1, Risk2 and Sum1, Sum2 criteria in order to study the effectiveness or develop new loyalty programs.

Entropy Maximization Criteria provides a strategy to diversify a customer portfolio.

The second direction of modification of model (2) is to deepen the study of the customer portfolio to the level of each individual outlet. Then the sum of the optimal customer portfolios of a particular outlet forms the optimal portfolio of customers of the pharmacy network as a whole. Let's introduce the following notation:

y_{k1} – the share of loyal customers in the portfolio of clients of the *k*-th outlet;

y_{k2} – the proportion of random customers of the *k*-th outlet;

y_{k3} – the share of Internet customers of the *k*-th outlet;

b_{ki} – the average check for the *i*-th group of customers of the *k*-th outlet;

$\bar{b}_{ki}$ – the expected average check for the *i*-th group of customers of the *k*-th outlet;

q_{ki} – the average frequency of visits in the *i*-th group of customers of the *k*-th outlet;

$\bar{q}_{ki}$ – the expected average frequency of visits in the *i*-th customer group of the *k*-th outlet;

n – the number of pharmacies in the network.

$$\begin{cases} Risk1 = \sum_{k=1}^{n\Sigma}\sum_{i=1}^{3}\sum_{j=1}^{3} y_i \, y_j (q_i - \bar{q}_i)\left(q_j - \bar{q}_j\right) \to min \\ Risk2 = \sum_{k=1}^{n\Sigma}\sum_{i=1}^{3}\sum_{j=1}^{3} y_i \, y_j \left(b_i - \bar{b}_i\right)\left(b_j - \bar{b}_j\right) \to min, \\ Sum1 = \sum_{k=1}^{n\Sigma}\sum_{i=1}^{3\Sigma} y_i \cdot q_i \to max, \\ Sum2 = \sum_{k=1}^{n\Sigma}\sum_{i=1}^{3\Sigma} y_i \cdot b_i \to max, \\ Entropy = -\sum_{k=1}^{n\Sigma}\sum_{i=1}^{3\Sigma} y_i \cdot ln(y_i) \to max, \\ \sum_{k=1}^{n}\sum_{i=1}^{3} y_i = 1, y_i \in [0; 1]. \{ \end{cases} \quad (3)$$

2.3 Portfolio model of optimizing supplies

We build a model of a portfolio of suppliers, for which the purchase prices for goods are taken – Model 3. In the process of purchasing medicines and medical supplies from suppliers, the pharmacy network seeks to minimize costs and select the right amount at the lowest possible cost. Each pharmacy must have a compulsory set of vital and social medicines in its range. At the same time, each pharmacy network seeks to maximize the difference between the retail price and the purchase price (margin). In addition, the Decree, 2019 [8] establishes four groups of medicines on the National List of Essential Medicines, for which regressive retail margins are formed based on the purchase price, including taxes, and do not exceed the following amounts: group of medicines l_1 – purchase price up to 100 UAH – 25% purchase price supplement, group l_2 – purchase price from 100 to 500 UAH – 20% purchase price supplement, group l_3 – the purchase price from 500 to 1 000 UAH – a supplement to the purchase price of 15%, group l_4 – the purchase price is more than 1 000 UAH – the purchase price supplement is 10% [9].

All this imposes certain restrictions on the formation of an optimal portfolio of goods orders for the pharmacy network. Other products in the pharmacy network that are not on the National List of Essential Medicines and are not covered by the purchase price premium are denoted as group l_5.

Let, g_{klf} – purchase volume of the k-th type of goods from the l-th group from the f-th manufacturer (pieces), K – number of types of goods, F – number of manufacturers, p_{klf} – purchase price of the k-th type of goods from the l-th group from the f-th producer (UAH), w_{klf} – the share of the f-th manufacturer of the k-th commodity from the l-th group in the pharmacy network purchasing portfolio, s_{klf} – the price of sale in the network of the k-th type of goods from the l-th group from the f-th manufacturer (UAH).

$$\begin{cases} Risk = \sum_{k=1}^{K}\sum_{l=1}^{5}\sum_{f_i}^{F}\sum_{f_j}^{F}\left(p_{klf_i} - \overline{p}_{klf_i}\right)\cdot\left(s_{klf_i} - \overline{s}_{klf_i}\right)\cdot w_{klf_i}\cdot w_{klf_j} \to \min, \\ Sum1 = \sum_{f=1}^{F}\sum_{l=1}^{5}\sum_{k=1}^{K} p_{klf}\cdot w_{klf} \to \min, \\ Sum2 = \sum_{f=1}^{F}\sum_{l=1}^{5}\sum_{k=1}^{K} s_{klf}\cdot w_{klf} \to \max, \\ Entropy = -\sum_{f=1}^{F}\sum_{l=1}^{5}\sum_{k=1}^{K} w_{klf}\cdot\ln\left(w_{klf}\right) \to \max, \\ \dfrac{s_{k1f} - p_{k1f}}{p_{k1f}} \le 0.25,\ p_{k1f} \le 100, \\ \dfrac{s_{k2f} - p_{k2f}}{p_{k2f}} \le 0.2,\ 100 < p_{k1f} \le 500, \\ \dfrac{s_{k3f} - p_{k3f}}{p_{k3f}} \le 0.15,\ 500 < p_{k1f} \le 1000, \\ \dfrac{s_{k4f} - p_{k4f}}{p_{k4f}} \le 0.1,\ p_{k1f} \ge 1000, \\ \sum_{f=1}^{F}\sum_{l=1}^{5}\sum_{k=1}^{K} w_{klf} = 1, \quad \sum_{f=1}^{F}\sum_{l=1}^{4}\sum_{k=1}^{K} g_{klf} > 0. \end{cases} \tag{4}$$

In this case, the risks are caused by fluctuations in the purchase and sale prices of medicines and medical supplies by different suppliers. Two criteria that meet the goal of maximizing profitability are Sum1 – the total purchase price that is minimized and Sum2 – the total cost of sales across the network that is maximized.

The solution to problem (3) will be the matrix $G^*=\|g_{klf}\|$, which is the optimum plan for purchasing the k-th product from the l-th group at the f-th manufacturer for a centralized pharmacy network.

2.4 Portfolio model for optimizing the set of goods for each individual outlet

Model 4. The formation of the product portfolio of each individual outlet takes into account the peculiarities of its geographical location (traffic, proximity to medical facilities, etc.) and the expected demand for goods.

Thus, for each pharmacy will be created a separate assortment portfolio, which is aimed at maximizing the satisfaction of demand for goods at each specific outlet. The risks diversified by such a portfolio are caused by fluctuations in demand for different commodities.

z_{ki} – the share of demand for the k-th type of goods in the total demand for the product portfolio of the i-th point of sale,

d_{ki} – demand for the k-th type of goods in the i-th outlet (UAH.) (Or another option is possible D_{ki} – the demand for the k-th type of goods in the i-th outlet (packages)),

$$\begin{cases} Risk = \sum_{i}^{n\Sigma}\sum_{k,m}^{K} z_{ki}z_{mi}\left(d_{ki} - \bar{d}\right)\left(d_{mi} - \bar{d}\right) \to min, \\ Sum = \sum_{i}^{n\Sigma}\sum_{k}^{K} z_{ki}\cdot d_{ki} \to max, \\ Entropy = -\sum_{i}^{n\Sigma}\sum_{k}^{K} z_{ki}\cdot ln(z_{ki}) \to max, \\ \sum_{i=}^{n}\sum_{k}^{K} z_{ki} = 1, z_{ki} \in [0;1].\{ \end{cases} \tag{5}$$

The solution to problem (5) will be the matrix $Z^*=\|z_{ki}\|$, which is the optimal plan for the distribution of demand shares for the k-th type of goods by the i-th outlets in a centralized pharmacy network (product portfolio).

Modifications to model (4) are also possible with the inclusion in its composition of the demand for goods expressed in the number of packages D_{kl}, as well as its deepening to the level of inclusion of the goods of the k-type in the l-th group, as shown in model (4).

The break-even condition is a balance between purchase costs and sales revenues, ie the volume of goods ordered must correspond to the volume of goods sold at all outlets of the network.

From models (3) and (4) we obtain the relation between the portfolio of orders from suppliers and the assortment portfolio of retail outlets of the network (in monetary units):

$$\sum_{k=1}^{K}\sum_{l=1}^{5}\sum_{f=1}^{F} g_{klf}\cdot w_{klf} = \sum_{i=1}^{n}\sum_{k=1}^{K} z_{ki}\cdot D_{ki}. \tag{6}$$

3 Solution of multicriteria problem of complex diversification by the method of successive procedures

We will consider in more detail the solution of multicriteria problems of complex diversification on the example of the first of complex models by the method of successive procedures [10].

3.1 Solution of optimizing the distribution of finances

The sequential assignment method for multi-criteria problems is applied when partial criteria can be ordered in decrease of their importance. To choose a diversification strategy, we choose the following ratio of order: Entropy – Sum – Risk.

In the first step, let us determine the optimal value of the first *Entropy* criterion in the valid solution area.

$$Entropy: -\sum_{i=1}^{n\Sigma} x_i \, ln(x_i) \to max$$
$$\begin{cases} \sum_i^n \bar{a}_i \cdot x_i \geq 2 \cdot 10^6 \cdot n, \\ \sum_i^n x_i = 1{,}0{,}001 \leq x \leq 0{,}9. \end{cases} \quad (7)$$

The optimal solution for the first partial criterion is $Entropy^*$. In the second step, we solve the conditional optimization problem on the next most important *Risk* criterion, adding to the conditions that determine the admissible solutions, the conditions for deviation of the first *Entropy* criterion from the found optimal value of $Entropy^*$ by no more than the value of the admissible assignment $\delta_1 > 0$. So we have the formalization of the second stage:

$$Sum: \sum_{i}^{n} \bar{a}_i \cdot x_i \to max,$$
$$\begin{cases} \sum_{i=1}^n x_i \cdot ln(x_i) + \delta_1 \cdot Entropy^* \leq 0, \\ \sum_i^n \bar{a}_i \cdot x_i \geq 2 \cdot 10^6 \cdot n, \\ \sum_i^n x_i = 1{,}0{,}001 \leq x \leq 0{,}9. \end{cases} \quad (8)$$

The optimal solution according to the second criterion Sum^* is obtained. Repeat the procedure for the next criterion *Sum*, adding to the conditions that determine the admissible solutions, the conditions for deviation of the first *Entropy* criterion and the second *Sum* criterion from the found optimal values $Entropy^*$, Sum^* not more than the values of allowable concessions $\delta_1 > 0$ and $\delta_2 > 0$.

$$Risk = \frac{2}{n} \sum_{i=1}^{n\Sigma} \sum_{j=i+1}^{n} (a_i - \bar{a}_i) \cdot (a_j - \bar{a}_j) \cdot x_i \cdot x_j \to min$$
$$\begin{cases} \sum_{i=1}^n x_i \, ln(x_i) + \delta_1 \cdot Entropy^* \leq 0, \\ \sum_i^n \bar{a}_i \cdot x_i \geq 2 \cdot 10^6 \cdot n, \\ (1 - \delta_2) Sum \leq Sum^*, \\ \sum_i^n x_i = 1{,}0{,}001 \leq x \leq 0{,}9. \end{cases} \quad (9)$$

The solution obtained in the third stage is the solution of the three-criteria conditional optimization problem (1). The experiments with the models were conducted on the real data of one of the pharmacy networks operating in the city of Zaporizhzhia. All calculations were performed in the Matlab package [11].

Figure 2 shows the optimal solutions obtained in the third step of the sequential assignment method for different pharmacy size networks: small $n = 5$, medium $n = 33$, and meganetworks $n = 65$.

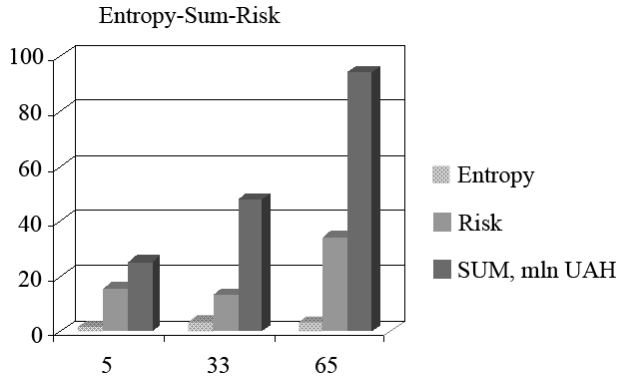

Fig. 2. Optimal solutions for different in size pharmacy networks.

Were built pareto-optimal portfolios. Figure 3 presents the two-criterion projections of the set of Pareto-optimal portfolios obtained for model 1 on real data on the turnover of retail outlets in the pharmacy network.

The black points "○"correspond to experiments that take into account the pharmacy's overall risk, which is the sum of its own and systemic risks.

The gray points "Δ" indicate a set of portfolios in which only systemic risk was taken into account.

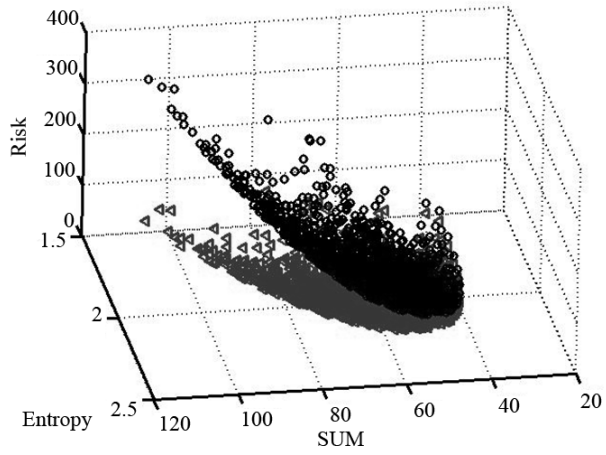

Fig. 3. Solutions to model (1) in the Entropy – Sum – Risk space built in Matlab.

Figures 4-6 presents two-criteria projections that can be followed by relevant Pareto boundaries, with pareto-optimal risk management portfolios.

The experiments in Matlab [11] with models for solving the corresponding multicriteria problems by the method of successive concessions showed that the order of criteria is important for choosing a diversification

strategy. The best results were obtained for this order: Entropy – Sum – Risk.

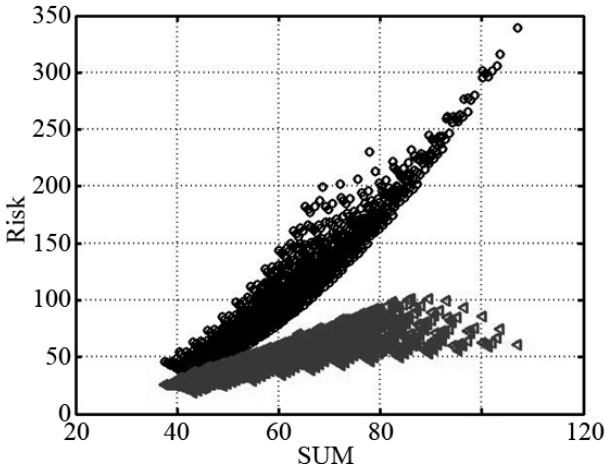

Fig. 4. Projection in Sum – Risk space.

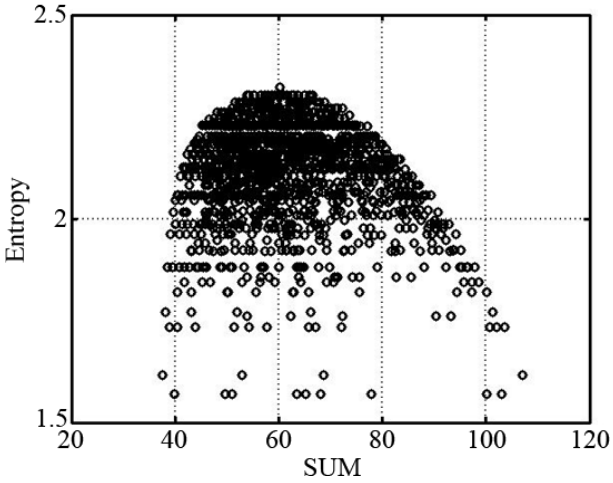

Fig. 5. Projection in Sum – Entropy space.

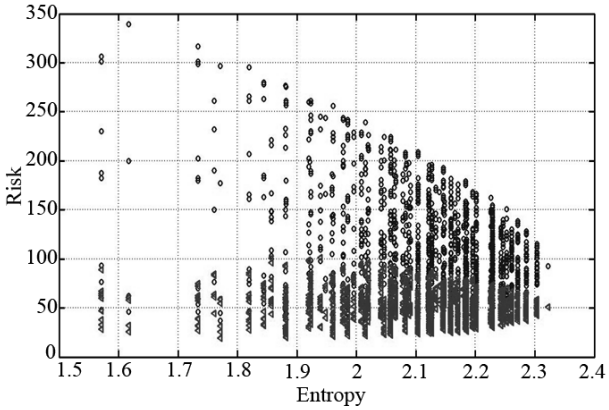

Fig. 6. Projection in Entropy-Risk space.

3.2 Solution of optimizing optimal combination customers

Experiments with models (model verification) were carried out on the data of one of the pharmacy networks operating in the city of Zaporizhzhia (Ukraine). Since there was no monitoring of the frequency of visits to customer groups by pharmacies, the study was carried out using a simplified model of the form:

$$\begin{cases} Risk = \sum_{i=1}^{3}\sum_{j=1}^{3} y_i\, y_j \left(b_i - \bar{b}_i\right)\left(b_j - \bar{b}_j\right) \rightarrow min, \\ Sum = \sum_{i=1}^{3\Sigma} y_i \cdot b_i \rightarrow max, \\ Entropy = -\sum_{i=1}^{3\Sigma} y_i \cdot ln(y_i) \rightarrow max \\ \sum_{i=1}^{3} y_i = 1, y_i \in [0;1]. \end{cases} \quad (10)$$

The case is considered when instead of a diversified portfolio of clients, preference is given to loyal customers. Let's replace entropy maximization with a criterion of the form: $1Loyal = y_1/y_2/y_3 \rightarrow max$

$$\begin{cases} Risk2 = \sum_{i=1}^{3}\sum_{j=1}^{3} y_i\, y_j \left(b_i - \bar{b}_i\right)\left(b_j - \bar{b}_j\right) \rightarrow min, \\ Sum2 = \sum_{i=1}^{3\Sigma} y_i \cdot b_i \rightarrow max, \\ 1Loyal = y_1/y_2/y_3 \rightarrow max \\ \sum_{i=1}^{3} y_i = 1, y_i \in [0;1]. \end{cases} \quad (11)$$

For a portfolio in which preference is given to random visitors, the criterion is used:

$2Loyal = y_2/y_1/y_3 \rightarrow max.$

For a marketing policy aimed at maximizing the number of Internet clients, let's use the criterion: $3Loyal = y_3/y_1/y_2 \rightarrow max.$

Similar studies are conducted for individual pharmacies belonging to the same network, but have different composition of the initial customer portfolio.

For ease of comparison, the results of experiments are summarized in Table 1.

Table 1. The results of the experiment for centralized pharmacy network and individual pharmacies.

Initial conditions	**Strategy**	**Sum**	**Risk**	**Recommendations**
The network portfolio is dominated by on-line clients	Transition of the network to a diversification strategy	Increase	Increase	Recommended
	Change the composition of the portfolio in favor of the loyal, that is, develop loyalty programs	Increase	Increase	Recommended
Especially for pharmacies that have a large proportion of casual visitors in their portfolio	Separating the pharmacy from the network	Slight increase	Significant increase	Undesirable
Especially for pharmacies that have a large proportion of casual visitors in their portfolio	Pharmacy's transition to a diversification strategy	Slight decrease	Significant reduction in risk	Recommended

In more detail the modeling of optimal portfolio of clients of Pharmacy network and the results of the experiment are described in the paper [12].

4 Conclusion

Managing a pharmacy network in terms of digital transformation of the healthcare system involves the effective management of their own risks, minimizing them by diversifying their own activities, leading to new challenges and enhancing the relevance of research in this area.

The scientific novelty of this work is the formalization on the basis of portfolio theory and methods of multicriteria optimization of complex diversification models, taking into account the current conditions of functioning of pharmacy networks in a competitive market environment and changes in the legislation.

The practical value of the mathematical modeling performed in this work is confirmed by series of experiments conducted on real data, which demonstrated the possibility of using the developed tool for automatic distribution of resources of centralized pharmacy networks in the form of pareto-optimal portfolios in order to minimize risks. Among the areas of further research are conducting a number of experiments with different ways of formalizing risk in portfolio models and finding relevant analytical dependencies.

The developed models are universal, focused on accessible data, which are monitored by the internal audit of any pharmacy network.

The work was carried out as a part of the research work "Mathematical modeling of socio-economic processes and systems", the registration number DB05038, at the Department of System Analysis and Computational Mathematics of National University "Zaporizhzhia Polytechnic".

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Sprinting for creative economy growth – a case study of a business planning and rapid prototyping toolkit for the Brazilian creative economy sector

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Abstract. This article reflects on the development of a creative economy training product and toolkit developed by Coventry University with SEBRAE (the Brasilian Micro and Small Business Support Service) and funded by British Council. It was devised following two weeks creative economy scoping visits in autumn 2017 in Brasil. The scoping visits identified the need for a fun and "disruptive" business planning experience leading to rapid prototyping which would allow new creative economy ideas to be brought to market at low development cost – "Sprint". A one day micro Sprint was tested in four locations in Brazil to excellent feedback in late 2017. The client subsequently requested a three day version of the methodology to invest more time in the cultural change of the creative entrepreneur and the development of an associated toolkit. However, this Sprint has subsequently also been rolled out in a super condensed 3 hour version piloting in 2019 and 2020 in Ukraine through British Council Creative Spark programmes. The toolkit offers skills and techniques to train creative entrepreneurs and their mentors in enabling the growth of the creative economy in their communities. This paper predominantly focuses on the implementation of the client commissioned three day Sprint.

1 Introduction

*"*Every idea is a product of thinking and every product is the manifestation of idea naked in a thinker's mind" [1].

In this era of extraordinary change and globalisation, many acknowledge that creativity and innovation are now driving the new economy. Creativity has become a powerful source of competitive advantage and a driving force for progress. Organisations and even economic regions that embrace creativity generate significantly higher revenue and provide greater stability into the future [2].

The modern form of globalisation determines a new plane in which cultural practices interact with creativity and innovation on a global scale shaping in such a way a new sector of the economy – creative industries. This encompasses economic activities concerning the generation, exploitation, transformation, dissemination and commercialisation of information and knowledge and bringing significant economic and social impacts (for example driving sustainable development and inclusive job opportunities). Therefore, the creative industries are converted into a stabilising element of country's competitiveness [3].

Developed countries around the world have now transitioned into functioning within a knowledge economy where information and knowledge are important drivers of economic growth. As we navigate this move to a post-industrial knowledge economy, from an economy solely based on the production of goods to an economy significantly fuelled by ideas and innovation, the role of creativity in shaping and driving that growth can no longer be ignored. The creative economy can also be seen as revitalising manufacturing through the interaction of creatives with advanced manufacturing [4].

If we are to thrive in business we must be creative. Business is a creative activity. Success in entrepreneurship today demands constant innovation. [5]. Generating fresh solutions to problems, and the ability to invent new products or services for a changing market, are part of the intellectual capital that gives an organisation its long-run sustainable competitive advantage including engaging with Industry 4.0 [6].

This teaching case study provides an outline of how creative entrepreneurs and sector consultants can run a Sprint with creative economy consultants and with creative entrepreneurs. However, more widely it outlines an adapted "Rapid Prototyping" tool that can be used across sectors to establish a "Minimum Viable Product" [7].

Funded by the British Council and developed by Coventry University in conjunction with SEBRAE in Brasil, this three day Sprint approach and toolkit results from two weeks of creative economy scoping visits. These were conducted by Dr Richard Tomlins in Alagoas, Pernambuco, Minas Gerais and Rio de Janeiro

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in Brasil in autumn 2017. The funding sought to lever expertise and leadership from the UK Creative Economy sector to the benefit of its counterpart in Brasil. Throughout 2019 we began rolling out the same approach as part of a pack of playful methodologies in Ivano-Frankivsk, Ukraine also funded by the British Council. This work will continue in 2020.

We outline below the overall context of the creative economy for the project and the British Council's overall and Brasil specific approach before outlining the component parts of the published version and a further condensed version**.**

2 Context

"The future is already here. It's just not evenly distributed yet." [8]

Creativity can be described as "an inexhaustible resource based mainly on the ideas and cultural characteristics rather than on the physical capita". The sources of creativity include talent, personal emotions, knowledge, intuition, imagination, the ability to produce new ideas, and to solve problems as well as the cultural assets of each society (traditions, cultural values and heritage) [3].

New knowledge and creative skills which lead to disruptive innovation and are the most powerful drivers of economic growth in the modern economy, are formed at the intersection of fields and cultures. Over the past few years, more and more innovation spaces, ideation hubs, incubator labs and coworking spaces were designed to inspire people from diverse cultures and fields of expertise to interact with each other and foster creativity. The first who recognised the significance of such spaces were global companies like Google, Twitter and Facebook which provided their offices and campuses with inspiring creative infrastructure for their employee. Governmental structures at all levels, industry corporations, educational establishments and research institutions have started providing similar environments for the general public [9].

The modern creative environment is rich in different innovative forms of drivers of entrepreneurship like clusters, hubs, coworkings, business-incubators, accelerators, which became the strengthening power for regional competitiveness and economic growth. Thus, idea generation needs a combination of skills, knowledge, talented individuals, and above all a good inspiring creative environment [10].

The creative economy has boomed in the UK over the last decade in economic terms stimulating increasing policy and academic inputs and increasing interest in the way in which creatives and innovators add value not only through a "badged" set of industries but also as part of the wider economy.

The British Council has been and is part of this process, in addition to providing the funding for our Sprint. A charity but also a public body it has as part of its remit to promote cultural relationships and understanding [11]. It sees the creative economy as not only an economic instrument but a path to greater well-being and community cohesion [12].

SEBRAE our original Brasilian funding partner also recognises the importance of this sector with specialist resources targeted at its growth [13]. In Brasil the Minister of Culture has stated that the cultural and creative activities already represent 2.6% of the Brasilian GDP, generate one million direct jobs and encompass more than 200 thousand companies and institutions. Nevertheless, "there is a great potential for growth and this involves the internationalization of our talents and of our valuable cultural production" [14]. As our work moves to Ukraine we are seeing similar drivers and interest.

Despite this enthusiasm it is not always clear if we are talking about the same thing as creative economy. In Brasil different states clearly had different creative economy priorities and potentially definitions.

Does this matter?

It certainly became material to us in project design as we "tore up" the project plan from the winning bid which would have deployed subject experts to deliver specialist expertise in favour of the more generic and we felt far reaching rapid business prototyping.

3 Project scope

The Invitation to Tender for this project was designed to expand British Council Brasil's creative economy activities beyond pilot activities in São Paulo.

It commissioned UK creative economy "expertise" as a catalyst for growth in its Brasilian counter-part and for wider cultural exchange with the UK. This reflected a commitment from all parties to co-design and co-production to deliver expertise and drive inclusive change.

The target outcomes were to:

- generate business and technological development.
- carry out capacity building targeting the creative economy industries.
- reduce economic inequalities among young people living in remote and low-income areas.
- integrate knowledge of the creative economy culture into SEBRAE's networks and programmes supporting;
- vulnerable populations,
- promoting economic opportunities
- social development in local contexts.

These targets sat within an overall aim to provide participants with expertise and confidence, enabling them to train and mentor creative entrepreneurs (or potential creative entrepreneurs) from marginalised neighbourhoods.

4 Why Sprint?

Our winning British Council tender proposed specialist creative economy support based around the specific creative expertise that each project location demanded. We also proposed to work with delegates to identify the social value [15] that they not only produced but also

could produce to future proof them against future budget cuts.

However, our scoping visit identified that we could add greatest project value through using Sprint as a creative, fun and time focused rapid prototyping tool. This would offer particular benefits to creative entrepreneurs who found aspects of traditional business planning inaccessible.

The social value element was retained as a thread through different sections of the Sprint toolkit to address the specific needs of "vulnerable populations" and the inequalities that they face.

Sprint sits firmly in the design thinking pedagogy and whilst describing itself as a "greatest hits" [16] of business thinking we see it as a commodification and branding of design thinking in a particularly accessible and intuitive way. It is driven by empathy and (re)-iteration although we were keen in delivery to ensure that empathy was not pejorative in the context of our emphasis on co-design and co-production.

We felt that we could offer an innovative, fun, compressed and productively disruptive business planning experience through Sprint playfully meeting the needs of creative entrepreneurs. This would build on Coventry University's work developing the Google Ventures Sprint concept including micro Sprints to produce rapid prototypes of products and services with minimum resource investment. The discipline of time constraints and quick decision making are crucial to the process of cultural change to achieve the prototype forcing people to bring an idea to fruition.

Google Ventures wrote Sprint as a 5 day workshop, nevertheless in our work we have experimented and successfully delivered a one day Sprint programme in Brasil and subsequently 3 hour versions in São Paulo and 2 hour versions in Ivano-Frankivsk. However, the three day Sprint programme remained the British Council's preferred instrument for achieving a significant step change for the creative entrepreneurs.

5 Running the workshop

Numbers

Google Ventures recommends no more than seven people in each group, although you might have an extra facilitator. The process works on group creative energy. This could be an existing work team or a group of different creative entrepreneurs.

Time

The Sprint time needs to be blocked in the calendar. If team members can't make this commitment then they're not ready to Sprint. It will destroy the energy if participants drop "in and out" of the session. Facilitating the Sprint also means minimising distractions. No laptops, phones, or iPads allowed, other than the odd occasion they need to be used to look something up as part of the Sprint. The team needs to focus rather then multi-task.

Who should be on the Sprint team?

The facilitator

You need a facilitator for a Sprint to challenge assumptions, see possibilities and turn problems into opportunities. They need to keep the pace moving otherwise the Sprint will not work! Slow decisions sap energy and threaten the timetable and most importantly the momentum of the work. The facilitator will need to build in regular breaks to the programme and have the flexibility to end sessions early if attendees are becoming tired. For lunch, eat together if you can. We had our best results when the team bonded over lunch and took the energy of the morning session into the afternoon.

The decider

A "decider" is also needed as part of each work group, with the authority to decide what will happen going forward in the creative enterprise taking part in the Sprint. If you have à group of different creative entrepreneurs then you still need a decider agreed by the group to make decisions to keep Sprint moving with the speed that the process requires,

Drawing

Participants are going to do a lot of drawing as part of the Sprint and if you're the facilitator you are going to have to make sure that people in the majority of cases draw rather than write

6 Teaching notes (a three day Sprint)

Day one – from general policy and market context to the Big Opportunity

We began by outlining Sprint as a rapid prototyping tool in contrast with the wider and more strategic focus of tools such as Business Model Canvas (BMC).

Group introductions led into an ice breaker and ground rules – "no distractions!!" – before groups were asked to decide on their "decider".

We drew on our own scoping visit, but also the local knowledge of the creative economy consultants and attendees to outline overall market opportunities locally, nationally and globally for the creative entrepreneurs.

The second part of day one allowed creative entrepreneurs to define their Big Opportunity for addressing that challenge. Delegates had to frame this opportunity in broad terms to provide a range of possibilities any one of which could be prototyped by the end of day 3…and they had to draw the opportunity.

We were careful not to let the group wait too long to start drawing. There's no need to practice the drawing or sketch it in pencil first, in fact this becomes counter-productive by making the Sprint process too cautious or over-refined before it has had the change to be properly outlined! Similarly we wanted a picture at this stage that

conveyed an idea rather than an artistic masterpiece to be perfected.

We were careful to encourage all the group to be involved in the drawing process and to avoid some of the group opting out of the process. We encouraged different members of the group to work on different parts of the flip chart or identify how something can be drawn.

This drawing from some of our Recife Sprint delegates captured their desire to ensure that the local gastronomy offer could touch all of our senses – that the consumer would be immersed in its authenticity and significance.

The richness of the Sprint was demonstrated by the extensive range of prototypes from the above idea - from apps to artificial intelligence and immersive "real-time" experiences (figure 1).

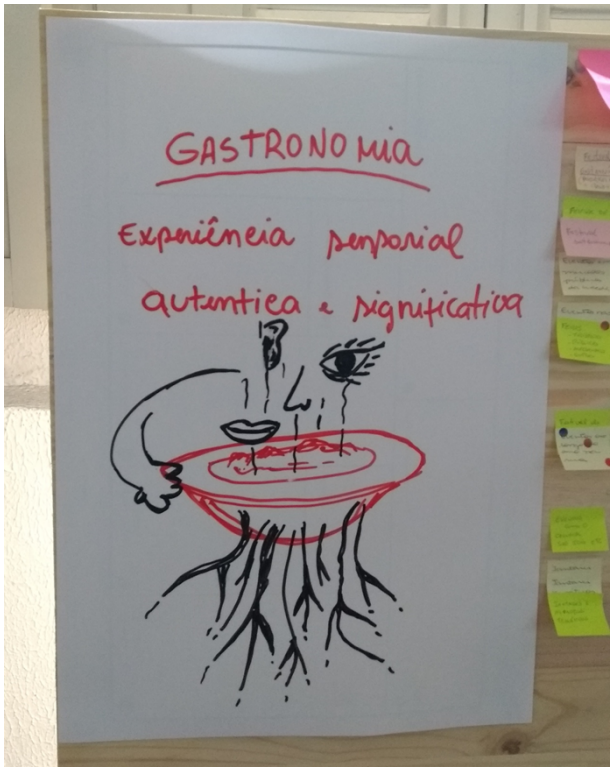

Fig. 1. Drawing from Recife Sprint delegates.

Identifying the target customer market

We got the group to pin their flip chart to the wall and asked the "decider" to present the opportunity to the rest of the room to make sure everyone was on the same page.

Finally for day one we got delegates to identify the three critical success factors for the prototype as a reference point for the final stage of day 3.

Day two required the creative entrepreneurs to consider, identify and of course draw their target customer market on a sheet of flip chart. We asked whether this was existing customers, potential customers, or both?

In our meetings with Samba Schools in Rio and Recife we discussed ways of widening their target market beyond the consumers of the Samba or Carnival event itself to wider music consumers. A new customer base related to their existing customer base.

We asked would the customer target market benefit from being segmented or were there synergies? For example, Instituto Cultural Polen's digital offer includes working with young people from favelas in Rio de Janeiro for example through its CriaAtivo Film School project. However, its wider digital work has drawn parents into working in the same space as their children increasing project footprint.

The facilitator had an important guiding role at this point for the Sprint group. We wanted Sprinters to focus on an identifiable group of potential customers, however for the market to remain viable in size. They had to consider how far to segment the target market. We asked was the target market local, regional, national or international? For example, we saw the way in which SEBRAE were working with different handicraft producers to increase their offer and visibility to collectors and international markets in our visits to Brazil.

Might delegates' target market be another business? In Alagoas one embroidery association Mimos de Dona Peró had identified one local artisan handicraft centre as a customer. Embroidered pieces were being incorporated into the clay master maker pieces and adding value.

Might the target market be potential investors and/or Government? In Minas Gerais, the State Government was interested in working with the emergent film industry to grow the Audio Visual sector.

Sprinters should end with something like our visitor to Recife as a visual reference point for the actions that they need to take (figure 2).

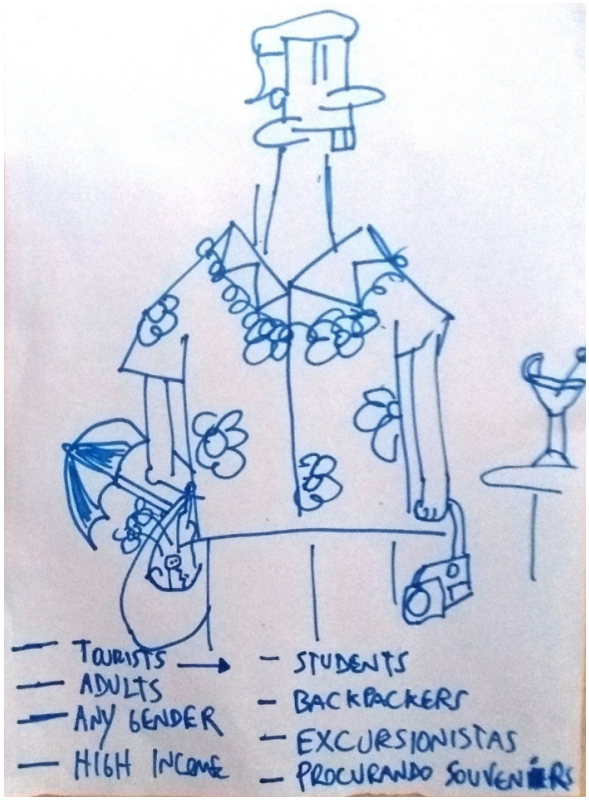

Fig. 2. Drawing from Recife Sprint delegates.

We got delegates to pin the flip chart drawing to the wall near to, but not next to the key idea or challenge. They had to fill in the gap next between this drawing and the Big Opportunity with more drawings showing how they were going to achieve that opportunity!

The second half of day two was delegates' (only!) chance to write rather than draw over the three days.

In fact, by the end of the afternoon they identified the service or product that they would prototype on day 3 to realise their Big Opportunity. They did this through a "how might we" exercise, writing on large post it notes as many ideas as they could think of for reaching their target market.

We made them to do it quickly to produce a rapid cascade of ideas, written with a marker pen to ensure that they didn't overload the "post it" with too much detail. We got the delegates to do the task individually and in silence! We didn't want "group think", we wanted a cascade of ideas.

Delegates were asked to stick the "post it" notes on a sheet of flip chart or just the wall next to the key challenge flip chart.

The more ideas and post – its the better. At this stage we asked the delegates to organise all the HMW notes into themes so that it was easier to focus on the merits of each idea, whilst emphasizing that they shouldn't worry about perfecting the themes, the exercise was a means to an end not to be graded!

Next we got the delegates to prioritise the most useful HMWs by voting on them – in silence – with sticky dots. At this stage it's the HMWs that they think have the best chance of realising the Big Opportunity that should get the votes.

Why silence?

We were again trying to avoid "group-think" and ensure that the quieter members of the group were "heard". Delegates got five dots each, although they could only put one on any one HMW post it note including any of their own ideas! We hurried the group along to get dots on post it notes to avoid "paralysis by analysis". Where there was a tie in the "dot voting" then the "decider" made the decision on which idea to prototype to keep the prototype moving. The HMW idea with the most dots was the one that the group went on to prototype.

The remainder of the HMWs become a portfolio that Sprinters could return to and test at a future time or even within the three day Sprint if the timetable allowed.

Day three from storyboarding to prototyping

The morning of day three was drawing out as a storyboard how to put the chosen HMW idea into practice. This was delegates' guide to the key features that they needed to include in the prototype later that day.

The storyboard gave the creative entrepreneurs time to consider and specify what the prototype product or service would look like.

To achieve this Sprinters individually brainstormed how they could realise the chosen HMW idea from day two. This was another silent task to avoid "group think" and we used the "crazy eights" technique to achieve this goal. Blank paper and marker pens were handed out to all participants. This involved asking everyone to fold a sheet of paper in half 4 times. We then gave 30 minutes total for each delegate to draw eight rough sketches (one per folded panel) of how they might realise the group's chosen HMW idea. Throughout the exercise we continued to remind people of the time and made sure that it was clear which sketch they should be on.

When time was up we got each delegate to cross out the four ideas they liked least. Then we got each delegate to choose the idea they liked the most. Once everyone in the group had decided on their own preferred way of taking their key idea to the target customer market we got each member of the group to pitch why their proposed way forward should be adopted, storyboarded and produced by the whole of the group. Sprinters then decided which one of all the proposals to prototype. We asked the decider to decide if the group couldn't reach consensus!

Once the Sprint group had agreed on one proposal to put the "how might we" into practice then delegates were ready to storyboard. This time we got them to draw eight squares on a flip chart and fill them in as a storyboard…like a comic strip if you prefer. This provided a blueprint for the prototype that they would develop. As facilitators, we were helping the Sprint crowd to draw out the idea whilst literally drawing it!

The best storyboards that we saw brought out the passion and emotion of the creative experience – purely from the storyboard. They could show a visitor's emotions as they navigated around a museum. For example, the Memorial Luiz Gonzaga in Recife evoked a journey for us with its narrative of the life of one of the great Brazilian musicians and of the popular culture of North East Brazil. If you were storyboarding its offer to the customer then you could "walk" us through the feelings of moving from exhibit to exhibit. An alternative way of storyboarding could be to represent the different facets of a product or local projects. However, quite simple storyboards led to powerful prototypes (figure 3).

Prototyping

The second stage of day 3 was building out the storyboard so the Sprinters had a prototype creative economy product or service. Naïve or sophisticated, it simply needed to be good enough to convey the essence of the idea so that we can judge whether it is a viable idea to take forward as part of Sprinters' "offer".

We get and got sprinters to use whatever materials were in the room without insisting on the perfect resource, to avoid spending more time than we would want to produce the "perfect" product. We wanted to avoid the trap of "perfection is the enemy of innovation".

We had a mobile phone "app" from Alagoas that didn't even require tech – it was built of paper and card! However, we did let Sprinters use laptops and cell phones to at this stage to downloading apps and

software, although some built apps simulated from Power Point or Keynote.

Fig. 3. Storyboarding from Belo Horizonte Sprint delegates

Some made complete films…including occasionally with their lunch and a stray Business Model Canvas (Figure 4).

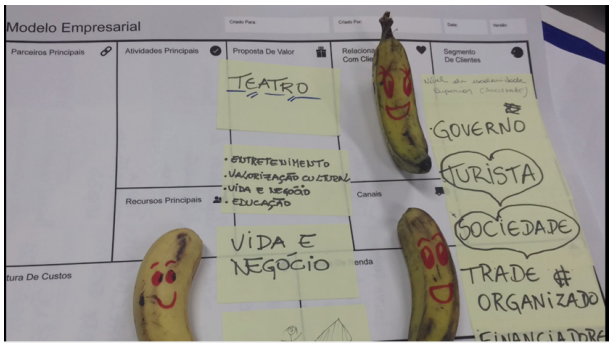

Fig. 4. Alagoas' delegates lunch rapid prototyping.

Sprinters had to present their prototype to us. They already knew what their ideas were or at least thought that they did, however this task ensured everyone was on the same page. They might have instinctively known at this stage whether the prototype is viable to develop further. However, we asked the delegates to also review whether the prototype met the 3 key success factors that they set out on the first day.

When they'd done this we tasked them to plan next steps! Each delegate wrote down how they were going to implement the learning from the Sprint as a "SMART" action plan to implement the prototype.

Where there had been a group of different creative entrepreneurs, the next steps were shaped by how far they had produced a prototype that was relevant to all of them and/or inspirational to all of them. Nevertheless, they still had a process to reshape the offer of the creative entrepreneurs that they worked with and for them to brainstorm new prototypes themselves.

Post Sprint the SMART action plan included ensuring that the prototype was tested with its potential market before being brought to market.

7 Conclusion

Two of us ran each Sprint although it could have been facilitated by only one and we have done this going forward. We were an experienced Sprinter and a novice - even a slight sceptic!

The process of rapid prototyping and achieving it through drawing as part of a Sprint achieved all our project objectives to facilitate the Brasilian creative economy. The feedback from the pilot sessions was phenomenally good and the Sprint methodology is now being rolled out through SEBRAE [17].

We started wedded to the precise Sprint methodology [16] and ended disrupting a disruptive methodology! However, this was in one country and one continent and we are now looking to inform and develop our methodology with colleagues from Ivano-Frankivsk National Technical University of Oil and Gas. In essence how far is the methodology transferable…early results from Ukraine are promising.

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Couchsurfing as a virtual hospitality network and a type of sustainable youth tourism

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Abstract. The modern tourism diversity coursed by the emergence of its new varieties is sure to evolve with a view to the goals of sustainable future. The article is dedicated to couchsurfing, a kind of sustainable youth tourism, a global hospitality network, as an online service used for transcultural communication of tourists through the organization of various assistance during joint travel. It helps meet tourists' recreational needs and travelling at no charge. The article considers the organizational structure of couchsurfing as a network managed by regional units. The authors identify the factors that influence the development of this type of tourism (globalization of the world economy, the development of the Internet, the growth of human well-being, democratization of society and etc.). They offer a comprehensive classification of types of couchsurfing by several criteria (age of tourists, number of participants, purpose of the trip and direction, length of stay, intensity of tourist flow). The regional peculiarities of the couchsurfing development are identified, and the regions with high (Europe, Anglo-American, Australia and New Zealand), middle (Asia and Latin America) and low levels of its development (Africa, Oceania and Central America) are distinguished. The map material illustrating the spread of couchsurfing around the world is created.

1 Introduction

1.1 The problem statement

In an age of globalization social life undergoes significant changes: human relations become more open, interstate borders gradually disappear, and travel and tourism gain in popularity, especially among young people.

Tourism has grown rapidly over the last half-century, becoming one of the most profitable sectors of the economy. At the same time, the development and diversification of tourism must take into account the goals set out in the 2030 Agenda for Sustainable Development and the SDGs on the period up to 2030 [1] and should contribute to the achievement of all components of sustainable development and sustainable future. Today, sustainable tourism has become one of the priorities of the United Nations World Tourism Organization.

Simultaneously according to Snizhana Neklyudova and Valeriy Cabrin "changes in tourism are connected with the development of modern technologies, the Internet, transport, and on the other hand, changes in the nature of tourism and tourists behavior – have led to the emergence of new forms of tourism and ways of traveling" [2]. In search of new destinations and types of tourist recreation, young people are already actively mastering one of these forms – couchsurfing.

In general, sustainable development guidelines and sustainable development management practices are applicable to all forms and types of tourism, so couchsurfing is no exception.

1.2 The objective of the article

The purpose of the proposed publication is to characterize couchsurfing as a type of youth tourism and the most popular modern global hospitality network. We also briefly consider the contribution of tourism and couchsurfing as its type to the Sustainable Development Goals.

1.3 Theoretical background

Tourism as a subject of research has been considered in scientific works for a long time, because over the long history of the development of human travel there are peculiar forms of hospitality.

However, as noted above, in the information society, traditional varieties of hospitality are taking on new content and new forms [3]. Virtual hospitality networks have become one of these new phenomena, and couchsurfing is one of the most popular, but at the same time the least researched one.

A theoretical generalization of the scientific literature makes it possible to argue that couchsurfing (couch – a type of high bed, especially one in a doctor's office, and surfing – traveling) is a global hospitality network that exists as an online resource (Couchsurfing.com [4])

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similar to a social network that offers its users a search platform (for searching housing, dating, events and travel partners) to meet your recreational and travelling needs at no charge.

So couchsurfing is a new, non-profit hospitality form of tourism that has become increasingly popular in recent years as it allows you to achieve your goals while saving significantly on travel. However, saving money is not a priority.

Couchsurfing is a social phenomenon based on trust, gratitude and willingness to help. The number of people participating in this community is increasing every year. Such a social phenomenon surely could not be ignored by scientists.

Coachsurfing has become the subject of scientific research relatively recently. The beginning of the scientific study of couchesurfing can be considered the work Cosmopolitans on the Couch: Mobile Hospitality and the Internet (2007) [5]. Jennie Germann Molz, exploring mobile hospitality and host-to-guest relationships through the Internet, points out that couchsurfing is not about housing, but rather interpersonal relationships that can be the subject of special research – the intersection of online and offline worlds.

Mutual trust as a basis for couchsurfer interaction is emphasized by such researchers as Debra Lauterbach, Hung Truong, Tanuj Shah and Lada Adamic [6].

The scholars from University of Michigan (in Ann Arbor) Devan Rosen, Pascale Roy Lafontaine, Blake Hendrickson [7] offer a concise but at the same time meaningful definition of coaching: CouchSurfing.com is an online cultural exchange community in which members from around the globe coordinate travel accommodations and organize gatherings with fellow members via a social media platform. The authors emphasize that a sense of belonging to the community is the most characteristic of the people often attending local coaching meetings.

Studying the specifics of couchsurfing, it is extremely important to consider the safety of travel and trust in the CouchSurfing.com network, which is noted by scientists, including Clare Toeniskoetter [8].

Vicky Steylaerts and Sean O 'Dubhghaill [9] in their work *CouchSurfing and authenticity*: *Notes towards an understanding of an emerging phenomenon* (2012) draw attention to the nature of the phenomenon under study. They consider couchsurfing to be a modern trend, an authentic form of travel, and try to find the boundary between globalization and authenticity, analyzing both the positive and negative individual experiences of couchsurfers.

The Ukrainian couchesurfing researcher Lyubov Bozhko [3] also stresses that the leading idea of couchsurfing is to activate intercultural exchange and socialize in a friendly informal atmosphere. Such communication will allow representatives of different cultures and nationalities to look at problems in a different way and to learn tolerance.

The problematic field of the studied phenomenon is not limited to the aspects discussed above. Detailed research should be carried out on the organizational structure of the virtual hospitality network, the factors influencing its development, classification of types of coaching, identification of regional features of its distribution, which are considered in the article.

1.4 Research materials

The information base of the study is statistical and analytical documents: materials from the official site Couchsurfing.org., data from the UN statistics department, as well as reports and statistics from various couchsurfing companies and their branches, publications in magazines, newspapers, Internet networks and other information resources that are freely available.

2 Results and discussion

Nowadays the Couchsurfing community is the largest hospitality network and a new type of youth tourism that is rapidly gaining popularity worldwide [10].

The network is positioned as a place of social interaction and an effective means of finding free housing while traveling.

The Couchsurfers community is an institutionalized informal hospitality practice that allows people to socialize anywhere in the world [5].

The Couchsurfing service was founded as a non-profit organization in the US in 2003 by Casey Fenton, who was planning to travel to Iceland. He sent emails to 1500 Icelandic students requesting shelter for an overnight stay because he did not want to stay in an "uninteresting" hotel. Casey received more than 50 positive proposals, which prompted him to seek organizational solutions to this issue.

Couchsurfing International Incorporated was established on April 2, 2003 as a non-profit organization in New Hampshire. On June 13, 2003, the domain name couchsurfing.com was registered. From that moment, the history of the site's creation began.

The site was launched in 2004 in collaboration with Daniel Hoffer, Sebastian Le Tuan and Leonardo Silver. Currently, Patrick Dugan is the general director and financial director of the company. The board of directors includes Casey Fenton and Daniel Hoffer, Sebastian Le Tuan and Leonardo Silver [2, 11].

The network has a rather complex organizational structure and is managed by regional units, which ensure its normal functioning and users smooth travelling. We have developed a schematic representation of its composition (Table 1), which demonstrates that leadership positions are provided by a leadership team that manages four major units, each of which has separate departments and is responsible for performing its functions.

From 2006 to 2011, the development of the website was aimed at creating Couchsurfing collectives – group meetings that lasted several days or weeks and gathered groups of coaches who worked together to improve the site.

Such meetings took place in Montreal, Vienna, Wellington and Quebec. We find such geography of events interesting because it covers coaches from

different parts of the world once again emphasizing the global nature of this project. Group meetings finished in 2011 as a result of the US federal government banning to use volunteer work in commercial enterprises. The ban also completely stopped funding for the site through donations. Funding is now made through investments from major global corporations and through participants voluntary contributions [11].

Table 1. Organizational chart of the structure of the couchesurfing units.

Leadership team	**Community operators**	Chat Coordinators (correspondence)
		Site member associations Management
		Ambassadors Management Department
		Membership service (consultation)
		Security department
	Product department	Software and hardware department
		Geolocation and Translation Department
		Department of Innovation and Development
		Department of Productivity and Creative Design
		Couchsurfing.com's security policy department
	External Relations department	Media department
		Sponsorship department
		Public Relations Department
		Strategic Marketing Department
		Couchsurfing Mission Propaganda Division
	External Operations department	Finance department
		Legality Management Division
		Human Resources Department
		Legal Department
		Couchsurfing Mission and Achievement Monitoring department

In 2011 the company was able to obtain nonprofit status through becoming a part of a nonprofit corporation incorporated in Delaware.

Thus, couchsurfing as a type of youth tourism has a long history of development, and in 15 years of existence has evolved into a network that meets the tourist needs of people, including the youth, and brings together more than 15 million people worldwide. Nowadays, the term "coaching" has become a common name for the entire hospitality exchange movement. Couchsurfing strives for international connections between people and places, creates educational exchanges, raises collective awareness, promotes tolerance and facilitates multicultural understanding. This type of tourism promotes life and outlook change, intercultural experience and exchange that cross oceans, continents and cultures [12].

Couchsurfing's mission is to "create an inspiring experience". The idea is to encourage intercultural exchange via people communication in a friendly informal setting. It enables to realize the natural desire to learn something new, to share knowledge and experience in different spheres of life. Particularly, through such communication people from different countries, representatives of different cultures and nationalities have the opportunity to look at numerous international problems from different perspectives, to learn tolerance [4].

The utilization of Couchsurfing.com resource includes mandatory registration. The users fill in a profile page listing personal information: workplace, training, philosophical views, skills they can teach, favorite music, movies and books, and add their personal photos and photos of their home they offer, if any [13]. The site makes it impossible to change your name and address after registration for the safety of other users.

Coachsurfers can search for hosts using several options: gender, language, age, and location, whom they send messages and agree on further action.

Reliable criteria for choosing the right couchsurfer are:

- positive feedback from both "surfers" and "hosts";
- number of couchsurfing trips made;
- user verification;
- hobbies, vital values that are relevant to each participant individually.

Unreliable indicators in choosing a couchsurfer are:

- lack of detailed personal information;
- several negative reviews;
- the last time of a user site activity;
- the length of a user site registration [13].

Users can publish their travel plans and receive temporary host offers. It is also possible to use a mobile application that allows you to seek asylum in a company with other nearby travelers.

For public communication on the site a forum is divided into groups. The group includes members united by common geographical location, interests, etc.

The features of coaching and network users should include:

- international, global, informal activities;
- intercultural communication;
- non-commercialized exchange of services;
- an authentic form of travel, alternative to tour operators and travel agencies;
- individual activity of the tourist;
- being nature-friendly;
- combination the achievements of globalization with authenticity, by combining online and offline worlds, interacting with local people in their daily lives;
- sheer learning interest as a motive for tourism;
- difference from the traditional type of tourism by motives of travel [11].

Thus, coaching turns from a tourist services searching network into a venue of cross-cultural interaction and human values exchange.

In the course of the research we create a comprehensive classification of types of couchsurfing by several criteria: age of tourists, number of participants, purpose of trip, length of stay, intensity of tourist flow, and direction.

1. By geographical principle, couchsurfing is divided into:

- local;
- international.

2. According to the age of tourists traveling, coaching is:

- youth (18-30 years);
- adult (30 years old)
- family (mixed age).

3. The purpose of the trip is:

- entertainment;
- event;
- adventure;
- pilgrim-religious purpose;
- nostalgia tourism;
- ecotourism;
- extreme tourism;
- weekend tourism.

4. By the number of participants traveling:

- individual;
- group;
- family coaching.

5. By the duration of the couch's stay with the host:

- short-term (up to 3 days);
- long-term (from 3 to 7 days).

6. By intensity of tourist flow:

- episodic;
- *periodic (or permanent).*

7. Upon receiving additional services. Within the given classification it is possible to distinguish the following types of coaching:

- House swap is a type of couchsurfing suitable for the adults, since its mandatory criterion is the availability of own housing for people who exchange. The type of accommodation is not important. The most important thing is that your housing requirements and the time of stay coincide with what other tourists are looking for. Sometimes the exchange package also includes a car and food additionally to housing [11].
- Cooksurfing is a type of couchsurfing that aims to share national cuisine recipes with others, simultaneously borrowing other cultures recipes.
- Homestay is a family guest house where you can not only spend the night or eat, but also get acquainted with the lifestyles and habits of the owners.
- Wuffing – a type of couch surfing that allows you to volunteer on eco-farms around the world, to try different agricultural work, to see the peculiarities of farming from the inside, to relieve stress, to practice language, to make friends and take a break from city life.
- Servicing is a type of couchsurfing that includes no more than two nights traveler stay. The main goal is communication and excursion. There are people among the hosts who do not offer accommodation, but are happy to spend time with the tourist, as an interlocutor and a guide.
- Gifting is a kind of couchsurfing, when a tourist makes up for housing by a gift brought from the native land of the tourist. Fridge magnet, a souvenir, a coin, national clothes, music disc, etc. may be presented as gifts. More valuable gift options are also possible.

The success of Couchsurfing social network is due to the facilitation of numerous human interactions worldwide, taking them from the virtual environment into the reality. In order to monitor the operation of the network, site moderators constantly monitor all events that occur there.

Based on the available statistical information [4], we have drawn a number of conclusions.

As of October 2019, 15015978 people are registered on the site. The ratio between the representatives of both genders is given below (Table 2, Fig. 1). In our view, this situation can be explained by the fact that men are less demanding about living conditions, the majority of them seek to experience extreme and are not as safety concerned as women, believing that they can successfully self-protect.

Table 2. Couchsurfing Community Gender Structure (2019) [4].

Gender	Number of participants, pers.
Males	7 463 420
Females	6 571 456
Others*	981 102
Total	15 015 978

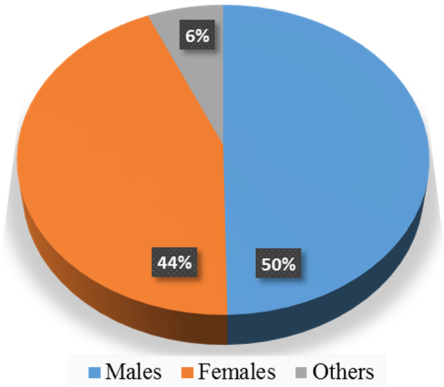

Fig. 1. Diagram of the Sexual Structure of the Couchsurfing Participants* (2019).

*others – are the ones who did not specify a gender when registering at CouchSurfing.com.

You cannot become a couchsurfer until you are 18 years old. This age is the limit on CouchSurfing.org. Active project participants are people from 18 to 79 years. The distribution of project participants by age is presented in Fig. 2.

The average age of coachers is 28 years. The most popular Couchsurfing is among young people aged 18 to 34 – 37,9 % of the total. People over 50 make up about 2 %. This proves that Couchsurfing is a type of tourism mainly for the younger generation.

We also find interesting the educational structure of the members of the couchsurfing community (Table 3, Fig. 3).

The largest share of couchsurfers (71 %) has higher education (bachelor and master degrees). The number of persons having high education is significant (24 %). If we consider couchsurfing to be a kind of cognitive tourism, it becomes clear the aspiration of people with higher education to get to know the outer world, to get acquainted

with new places and cultures, their need for communication with representatives of other social communities.

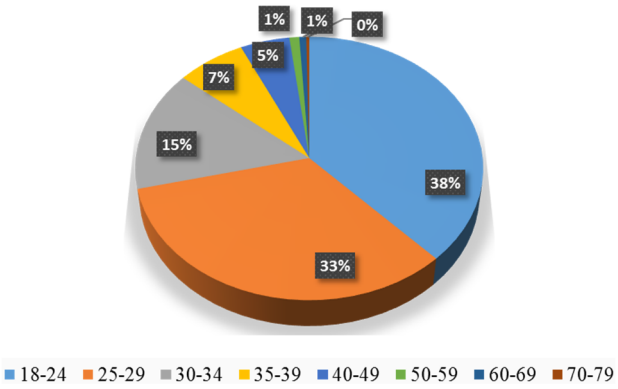

Fig. 2. Graph of Age structure of the couchsurfing community (2018) [4].

Table 3. The Couchsurfing Community Educational Structure (2019) [4].

Education	Number of participants, pers.
High education	3 663 835
Bachelor degree	8 829 267
Master degree	1 822 077
Post-graduate/ doctoral degree	140 160
Other	560 639
Total	15 015 978

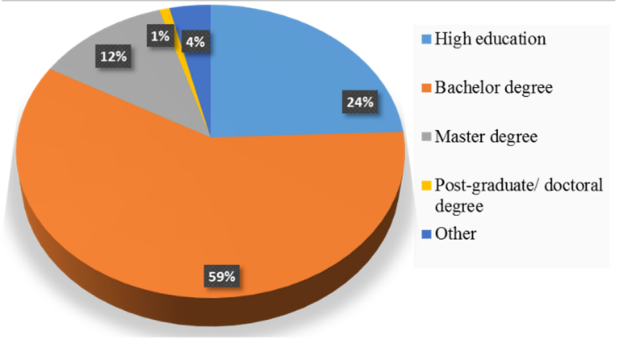

Fig. 3. Diagram of the Educational Structure of Couchsurfing Community (2019).

Couchsurfing is not only about hospitality but also about socializing, meeting new people and making new connections around the world. Therefore, the profiles of participants also provide information on what kind of services a particular coachsurfer can provide (Table 4). Hosts offering accommodation only make up 30,3 %, and the ones additionally offering excursions and walks are 16,8 % and 15,6 %. This reiterates the desire of the community members not only to provide (get) a place to spend a night, but also to learn something new, to make new friends, to show trevellers around the city, its architecture, history, and culture.

12,1 % of hosts with no conditions for long-term tourists can offer a temporary stay without accommodation. They are happy to meet couchsurfers for a cup of coffee, to give a city tour, and make them feel at home. However, most of the Couchsurfing participants are still able to accommodate tourists for the night.

Table 4. Type of hosting services (2019) [4].

Service	Number of participants, pers.
Overnight stay	4 544 953
Coffee or other beverages	3 783 515
Excursion	2 522 876
Walk	2 342 556
Temporary overnight stay	1 822 078
Total	15 015 978

We reckon the following factors contributed to the development of couchsurfing:

- globalization of the world economy, open borders;
- transportation development,
- the Internet, its rapid development and the social networks influence in society;
- the overall community well-being, that encourages travelling;
- democratization of society and liberalization of interpersonal relations, that stimulate people (especially youth) to refuse a planned package tour, map up an independent route of their own travel, international peers communication;
- change in the nature of tourism and tourists behavior, new forms of tourism and ways of travel.

Analyzing the statistics of the number of couchsurfers in the world for 2019 [4], we can distinguish the following groups of countries:

- With high number of participants (> 500 000 people) – Canada, USA, Germany, France, Great Britain.
- With enough (100 – 500 000 people) – Spain, Italy, Brazil, China, Australia, Ukraine and others.
- With an average number (20 – 100 000 people) – Peru, Republic of South Africa, New Zealand, Ireland, Tunisia and others.
- Low numbers (<20,000 people) – Bolivia, Panama, Mongolia, Iran, Estonia, Chad and others.

Couchsurfers have access to the most visited countries, the number of participants and the relationships between them, which is provided on the site [3, 10, 12]. Regarding the regional features of couchsurfing, the most popular regions include (Fig. 4).

Europe. Overall, there are the largest number of Couchsurfers in the European region. Inhabitants of this part of the world were the second after Anglo-America involved in coaching. But at present, Europe has a leading position in the number of countries with more than 200,000 couchsurfers (UK, Germany, France).

Modern tourism in this region is mainly cultural and historical and generally tours the Western sub-region. The Old World is the most tourist-friendly part of the world. European countries are very conveniently located to one another: common borders and a developed network of transport routes. EU countries are characterized by visa-free travel, that is why tourism in Europe is focused not only on foreign visitors from other continents, but also on its neighbors.

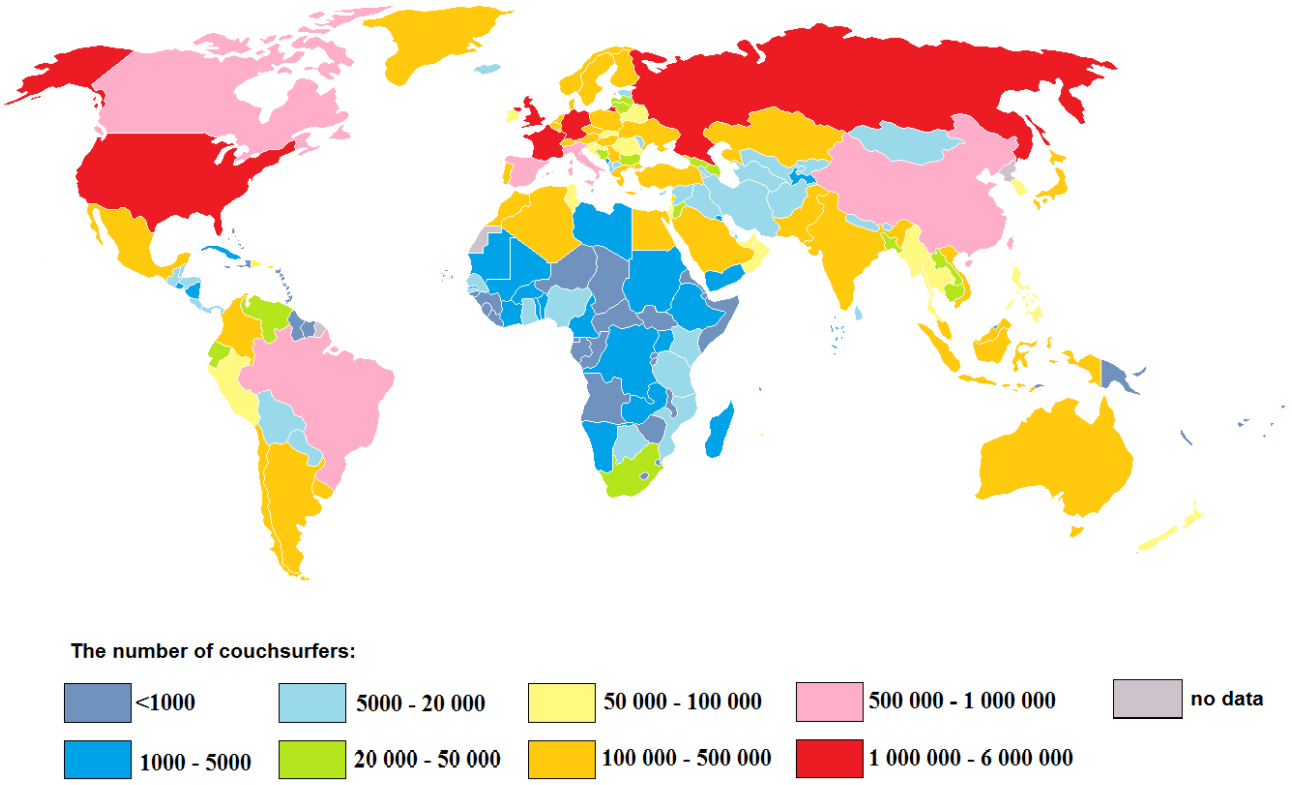

Fig. 4. Map "Number of Couchsurfers by Country (2019)" [4, 11].

Hosts in Europe offer comfortable accomodation, so family and adult coaching is also widely represented alongside with youth coaching [14].

The top couchsurfing destinations are the most famous tourist cities: Paris, London, Berlin, Vienna are in the top ranking.

The popularity of the European region among couchsurfers is due to: favorable geographical location; high level of socio-economic development; political stability; common currency; different types of tourism combination (cognitive, wellness, mountain-skiing and others); accomulation of tourist sites; education, kindness, openness of the hosts, and their willingness to provide everything necessary for a quality rest of their guests.

This type of recreation among the world's population is constantly urged in modern conditions.

Anglo-America. Anglo-American Region is the birthplace of couchsurfing. This is where this network came into being and rapidly developed. In terms of number of visits from abroad, it is inferior to the European region, but the number of local travels is very high there. The number of coachsurfers in Canada and the United States is 3 million [15].

Coaches visit these countries to admire the wonders of nature, vast cities, places of interest, filming of well-known films and TV shows, entertainment venues, long beaches, and to meet the indigenous people of these areas, to see their lifestyle. American hosts are mostly open, friendly, adventurous and active youth, seeking new acquaintances and intercultural exchanges, but offering predominantly modest overnight accommodations.

Coaches choose this region because of: the large number of Internet and Coachingsurfing site users; plenty of natural and anthropogenic sites and other places to visit; specific national charater of the Americans; high level of services, transportation and communication; a large number of youth events, festivals, concerts, parades, etc.; democracy and openness of society, government and law.

Couchsurfing leaders in the Anglo-American region are: New York City, Chicago, Washington, Montreal, Quebec, San Francisco, Los Angeles, Boston, and the others.

Australia and New Zealand. Despite the geographical isolation of these countries from the centers of coaching, more than 500 thousand people form this region participate in it.

The countries of the region are highly economically developed as well as the Western European countries. The development of tourism is facilitated by: a large number of natural and geographical advantages because of which couches come here (ideal beaches, sandy dunes, endemic organic world, Great Barrier Reef, etc.); urban landscapes, water parks, galleries, museums and festivals [16].

Coachsurfing has achieved the greatest development in cities such as Sydney, Wellington, Adelaide, Brisbane, Melbourne, Auckland, Christchurch.

So, couches travel to Australia and New Zealand because of the uniqueness and strangeness that hosts are happy to offer.

Thus, the popularity of couchsurfing in the above-mentioned regions (Europe, Anglo-American, Australia and New Zealand) is explained by the following general features: global distribution and the large number of Internet users; the desire to develop alternative types of tourism in order to gain new experiences, acquaintances, visit new places; high availability of recreational

facilities; mentality (credibility, friendliness, openness, etc.); free of charge services: accommodation, tours, communication, etc.

The average development of couchsurfing is in the following regions: **Asia** (leading countries in the number of couchsurfers are China (750 000), India (400 000)) and **Latin America** (the leading countries in the number of couchsurfers are Brazil (700 000 pers.), Mexico (400 000), Argentina (400 000) [4].

The countries of these regions have large territories and dramatically vary in the development.

Tourism is becoming an increasingly important item of income for these countries. Couchsurfers choose this region because it has: historical and architectural monuments; natural wonders, large in area and variety of flora and fauna of the nature reservations; picturesque metropolises; original traditions with a millennial history; specific reginal cuisine.

The main problem that hinders the active spread of couchsurfing in these countries is the huge disparity between couches and hosts, because not all couchsurfers are willing to have travelers for free. The reasons are very diverse – from worries about the hosts and their property safety, to psychological traits that cause anxiety and distrust in potential hosts to this type of journey. Political instability, national-ethnic conflicts, and infectious diseases should be attributed to the problems of the development of coaching in Asia and Latin America.

Thus, these regions have enormous potential for the couchsurfing development, but the locals reluctance or inability to receive couches prevent the spread of this type of tourism there.

Africa, the Middle East, Central America and Oceania are the least developed areas for couchsurfing. The reasons for this are: low socio-economic development of the countries of these regions; unstable political situation; lack or poor development of tourism infrastructure; the spread of dangerous diseases; unsanitary and other [11].

In **Africa,** there are generally up to several million couchsurfers in countries such as the Republic of South Africa, Egypt, Morocco, Tunis, Algeria and several other countries.

In **Oceania,** only one country New Caledonia have up to 500 couchsurfers, in other countries there are up to several dozen users.

In these regions, couches are attracted to virgin landscapes, the unique culture of the people who inhabit these territories. There is a tendency to increase the number of hosts.

Besides the positive aspects of tourism growth in general and couchsurfing in particular, which are described in the article above, there are also significant risks caused by worsening sociocultural, economic and environmental conditions of world destinations.

So, A. Seselkin [17] claims that tourism activities can directly or indirectly affect the environment; contribute to the depletion of natural resources, intolerant attitude to the culture of the visited country; violation of human rights related to the tourism sector; contribute to higher prices and economic instability, etc.

Meanwhile, tourism is one of the most promising growth stimulus for the global economy and, with appropriate investments, it can continue to grow steadily, contributing to the necessary economic growth, employment and development.

Couchsurfing as a global hospitality network and a kind of sustainable youth tourism is bound to reach such goals of sustainable development (SDGs) [18]:

- good health and prosperity (SDG No. 3;)
- sustainable economic growth, full and productive employment (SDG No. 8);
- reduction of inequality (SDG No. 10);
- rational consumption and production models (SDG No. 12), etc.

However, the contribution of tourism and couchsurfing is not limited to these goals, as it can directly or indirectly contribute to the achievement of all other Sustainable Development Goals [17].

3 Conclusion

1. Consequently, coaching is a kind of youth tourism with its specific features that make it different from other types of tourism (non-commercial, international, informal activities, free exchange of services, differences in travel motives, etc.), as well as characteristics that are common to many types of tourism (intercultural exchange through communication with people from all over the world, personal activity of tourists, deep interest in learning, the desire for recreation, etc.).
2. Moreover, the phenomenon of couchsurfing can be classified into the standard categories (age and gender of tourists, number of travelers, duration of travel, etc.), as well as special branches of the network (gifting, wuffing, homestay, etc.).
3. The development of couchsurfing in different countries has its own peculiarities: more developed countries attract many millions of tourists due to many appealing factors, in developing countries the number of tourists is less because of certain problems of various nature, but the fact that Couchsurfing annually attracts more and more followers is undeniable.
4. This study is open-ended and may continue to explore the historical and regional changes in the phenomenon of couchsurfing. In addition, the theoretical interest is primarily raised by the issues of economic and social models of exchange relations that underlie couchsurfing, the impact of market relations [2]. The practical problem is to determine how hospitality changes under the influence of innovative technologies, as well as to formulate a number of useful tips for beginners and experienced coaches.
5. We agree with A. Sesyolkin [17] and believe that the tourism sector can contribute to the achievement of sustainable development goals. At the same time, it is necessary to minimize tourism harmful impact on the environment and cultural heritage including.

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The content of training program for the teaching staff working with children of the labour migrants (in the context of sustainable futures)

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Abstract. The article deals with the ways of overcoming extreme poverty, poorness, starvation by providing quality education and well-being for labour migrants' children. These problems can be solved via teaching staff's work. The purpose of the article is to substantiate the content of the educational program for professional development of teaching staff to work with labour migrants' children and their social environment. Methods of research: theoretical analysis, synthesis, modeling, systematization, generalization. The results of the study: a set of approaches to the content of the program development; the content of the program; recommendations for its teaching. The conclusions of the study prove: labour migrants' children have problems that can be solved by interaction of teachers, social workers with the children's social environment; a new program for teachers is required; a set of scientific approaches is the basis for updating the content of the program; the educational program of pedagogical staff consists of the modules: "Problems of labour migrants' children"; "The system of GSEE work with labour migrants' children"; "Methods of GSEE work with labour migrants' children". The criterion of the effectiveness of the program and its purpose is the professional readiness of pedagogical staff to work with labor migrants' children.

1 Introduction

The relevance of the given article is related with:

1. The necessity to overcome such problems of our society (in the context of sustainable futures), as: poverty reduction, end hunger, good health and well-being, quality education for the labour migrants' children. Nowadays, parents in order to provide their families and children are forced to travel abroad or migrate within their country to achieve these goals for the benefit of their children, thus creating distant families which do not contribute to the best development and upbringing of their children in the family.

Visa-free regime to the countries of European Union (EU) for Ukrainian citizens, increased labour immigration of Ukrainian adults to the EU countries. The conflict in the East of Ukraine also contributed to increasing migration of families, which is proved by the number of about 1,600,000 officially registered internally displaced persons (IDPs). Ukraine ranks 8th in the world by the number of such persons. In this case, IDP adults leave their families in the peaceful conditions and search for the work in the Russian Federation and in the EU countries in order to provide families in Ukraine. In both cases we have children who grow up without 1 or 2 parents, and their closest surroundings are grandparents, godparents, distant relatives, neighbors and older siblings. Among the causes of mass labour immigration are poverty and poorness. Parents are forced to leave their children with relatives in order to earn money for their families. Migration can be either internal (about the country) or external (abroad). The struggle against poverty is one of the goals of the Millennium Development, and it ensures a sustainable society and its development. Therefore, the work of teaching staff at the general secondary education establishments with the labour migrants' children is aimed at overcoming poverty, assisting parents in the course of their children up-bringing, overcoming social orphanage with parents alive. As a rule, families of internally displaced person do not have homes of their own, live in difficult living conditions, including the places of compact living which we personally observed during the implementation of the EU project in Berdyansk in 2017, and where every 5th resident was internally displaced person. We have a significant increase in the number of labour migrant children. In order to work with such children teaching staff have to be trained in a new way at the general secondary education establishments (GSEE), since they have previously been trained to work with them under peaceful conditions.

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2. The necessity to achieve the following Millennium Development Goals: a) overcoming extreme poverty and poorness, because adult labor migration is caused by the inability to reach a decent living standard in native country or city, so as to provide sufficient level for children upbringing; b) improving maternity protection by creating conditions for mother and a child to live together and child up-bringing in the family, maintaining the "mother-child" ties, reducing the distance between families. 3) providing the general secondary education to children via creating conditions to exercise children's rights for education, representation of their legal interests by parents in education and daily life.

3. The labour migrants' children have significant problems in socialization, development, upbringing and education, life prospects, have psychological, social, legal problems, and their immediate surroundings have no right to represent the interests of children and protect their rights, as they are not responsible for these children. It is the right and duty of their parents who are absent during a long time [1, 2, 3, 4]. We have previously found out [5] that the closest social environment of a child and the teaching staff of the GSEE do not always understand the needs of such children and their problems, do not always even know about them, and cannot help to solve them, as children do not always respect teaching staff, and their functions are limited only by taking care of a child. The parents in the distance are interested only in their children's marks and what they have eaten. But unfortunately the parents are not interested in how children cope with their daily socialization problems, and how their children feel themselves.

The labour migrants' children are well organized at the general secondary educational establishments. Only the professional teacher daily sees them, and observes what is going on with a child. The teacher notices the changes that happen with the child and can quickly respond to problems as well as organize other professionals to help children. According to the order of the Ministry of Education and Science of Ukraine since 2007 all the children of labor migrants have to be registered and a special work should be conducted with them. Unfortunately, children often do not share the information that their parents have left for earnings. That is why, such children often communicate with the same children whose parents have also left for earnings in order to solve daily problems and problems of socialization [5]. In this case the role of teacher is especially great because they know about the problem. That is why there is a need in special teaching staff trained to conduct the necessary social work with labor migrants' children, as well as with their closest environment at the general secondary educational establishments. Previously the teaching staff have not been trained to such kind of work as well as to work with internally displaced person under conflict condition. All the participants of 4-days workshop within the EU project on "Creating a comprehensive system of assistance to internally displaced person from ATO zone to the community of Berdyansk" acknowledged everything above-mentioned in November 2017. All social teachers and school psychologists of the general secondary educational establishments attended that workshop. Workshops with children of labour migrants were conducted by "La Strada-Ukraine" International Women's Center in 2005-2007. Our work as a coach at workshop also proved the urgency of the problem as well as the necessity of special training for the teaching staff to such work, especially in border areas. Moreover, the lack of training courses on the problem is also vital. There is a need to train pedagogical staff to work with the immediate environment of children of labour migrants.

4. Changes in the living conditions of many children and their families as a result of the conflict in the East of Ukraine [6], which has led to family splitting, parents' mobilization, even to the death or injury of parents in the conflict. Such circumstances have also increased the children' stress due to their new roles in the family, such as: defender, helper, caregiver for young children and seniors, and other. These children lose a carelessness of a childhood and grow up early in some aspects. The teaching staff have not been previously taught to work with such war-stressed children. The psychological injuries used to be the focus of attention of psychologists and psychoneurologic dispensary. Nowadays, there are a lot of such children at secondary schools. They have to be taught and have their right for the education. So, there is a need for special training for teaching staff to work with such children, theoretical justification of the content and methods, forms of work with them.

5. The need to promptly improve the qualification of the teaching staff in the GSEE to work under new conditions of 30 hours per year (according to the Ministry's of Education of Ukraine new normative documents on the teaching staff further training in the general secondary educational establishments), instead of the previous one, which lasted for one month once in 5 years. New normative documents give the opportunity to train not only in the regional institutions of continuous education, but also in non-governmental organizations, pedagogical universities, etc. This gives an opportunity to introduce the program of the course consisting of 30 hours for pedagogical university, which has the license for further training, but the theoretical justification of its content, methods, and program modes, is required.

All above mentioned confirms that the updating of the training program content for the teaching staff working with the children of labour migrants at the general secondary educational establishments is highly required.

The theoretical analysis of the problem of further teaching staff training in order to work with labour migrants' children at the general secondary education establishments suggests that it was studied in the following areas:

1. Development of the general theoretical background for further teaching staff training [7, 8, 9], but without taking into account the problems of labour migrants' children, the conditions of current conflict in the East of Ukraine, current working conditions at the GSEE, and the reforms in the field of education. All above-mentioned implies the need to develop the content

of the program on the background of the theory of content education, competence- and activity-based approaches. At the same time, it is emphasized that internal displaced person's children and children of anti-terrorism operation warriors are the specific subject for further teaching staff training in the current conditions.

2. Training of the certain categories of the teaching and social staff to work with children of labour migrants [10, 11], problems of labour migrants' children [6, 12, 13], but without taking into consideration the dramatic increase of the problem, new working conditions of the teaching staff at the GSEE, and the need for their interaction in the interests of the children's rights support. These studies take into account the world's best experience in solving such problems. "La Strada – Ukraine" is an international organization, therefore it has collected and summarized the material on the problem worldwide with the assistance of the OSCE on migration, EU countries Funds, and the Council of Europe. It was the experience which at once has presented the problem at the level of state administration, and it has been considered in scientific, organizational, and methodological aspects. The studies were conducted in the regions [5]. The Ministry of Education and Science of Ukraine issued a special edict, teaching manual on how to work with children of labour migrants [11] was published twice (2005, 2007). A special training course on Family Economics was developed and introduced to those who planned to leave their families and children in Ukraine for working abroad. In 2006 this course was the most popular in the centers of social services for family, children and youth of Ukraine, especially among people under 35 in distant and economically depressed regions of Ukraine (according to the law social services were provided only on the basis of voluntariness and honesty).

But above-mentioned studies research the details of the problems of the labour migrants' children under peaceful conditions and the ways of problem-solving created in the GSEE, which involve teachers, psychologists, cooperation with children's services, social services centers for the family, children and youth, which should also be incorporated into the content of the program. Those researches were conducted in 2005-2007. The living conditions in society have changed dramatically, school has changed, migration has increased and its new kinds have emerged.

3. Teacher-training course to work with parents of students [11, 13, 14], to work with distant families [15]. But there are no researches on the teaching staff training to work with the immediate environment of children while their parents are absent. In general, researches in this area emphasize the teamwork of pedagogical staff with families in interests and rights of children, which require joint activity of social teaching staff, teachers, psychologists, and educational establishment's administration on the problem.

4. There are studies on sustainable futures of education both in Ukraine and abroad. R. Anderson [16], O. E. Vysotskaya [17], I. M. Korenova [18], V. R. Ilchenko [19] conducted their researches on the theoretical background of the reforms of education for sustainable futures, its content modernization, and taking in account the world's experience of reforms in education for sustainable futures. But these works do not cover and reveal the problem of working with labour migrants' children in the context of the goals of sustainable futures, and they do not mention the problem of further teaching staff training in order to work with such children.

The purpose and objectives of the study. Considering all above mentioned, the purpose of the article is scientific substantiation of the educational program content for further teaching staff training to work with children of labour migrants. The objectives of the article are the following: 1) theoretical substantiation of the educational program content for further teaching staff training to work with children of labour migrants; 2) development of the content of the regional educational program for further teaching staff training to work with children of labour migrants; 3) development of recommendations for the teachers on such program implementation.

2 Methodology

We have chosen the following materials for the given study:

1. Problems of labour migrants' children and IDP children, children of anti-terrorism operation (ATO) warriors, problems of realization of the right to education of the children in the countries with conflict, which we studied and summarized on the background of the researches conducted by "La Strada – Ukraine", scientific researches of Ukrainian scientists and public persons, international reports, reports of Ukrainian state organizations and human rights activists. The methods of generalization, classification, systematization, theoretical analysis, and synthesis have been applied for their description.

2. Regulations on working with labour migrants' children issued by the Ministry of Education and Science of Ukraine, current Ukrainian legislation on education and general secondary education, social work and social services, childhood care, which allowed to determine the responsibilities and rights of teaching and social staff in the work with the labour migrants children, the possibilities of their interaction, and to model their interaction in difficult life circumstances. Methods of scientific and pedagogical research, such as concretization, modeling, synthesis, induction, and deduction have been used.

3. Family Code of Ukraine, current family policy legislation in Ukraine and gender equality, which served as a basis for defining the rights and responsibilities of parents, the people who replace them, opportunities to interact with pedagogical workers in the immediate social environment. Methods of analysis, synthesis, modeling, systematization have been applied.

4. The scientific research on improving the further teaching staff training to work with children of labour migrants and their immediate social environment [7, 12, 20], classification of scientific approaches to social and

pedagogical phenomena to determine the concept of theoretical background for the development of the content of further training program [21, 22, 23, 24,25, 26, 27, 28, 29, 30, 31]. We have also analyzed scientific researches as to approaches to the content of education, androgynous studies to make recommendations as to the program content, and methods and forms of its teaching. Methods of classification, systematization, comparison, theoretical analysis and synthesis have been applied.

Professional readiness of pedagogical staff to work with children of labor migrants, and motivational criterion have been chosen as the criteria for mastering the content of the new course in the context of a competence-based approach (according to the current legislation on education In Ukraine). The first criterion involves professional competence of the teaching staff in the work with labour migrants' children at the general secondary educational establishments as well as the work with social environment of labour migrants' children. Motivational criterion illustrates the attitude of teaching staff to work with children of labour migrants. The indicators of the first criterion were determined as:

1) cognitive competence: knowledge of the teaching staff about the problems of labour migrants' children at the general secondary educational establishments, social environment of children, teachers' role and functions in their work with children, the basics of interaction in the interests of children with social environment and social workers, community, knowledge of the functions of children care services, knowledge of theoretical, legal, organizational backgrounds of work with children of labour migrants, system of work with them at the general secondary educational establishments, conditions of realization of children's rights to education;
2) operational competence: the ability to identify migrants' children, identify their problems, build relationships with migrants' children, their social environment, their community, social workers; to organize work in the interests of children's rights, create conditions for the realization of their rights.

Considering our own work experience (2017-2018) in a host IDP community with social teachers and school psychologists, social workers, as well as La Strada seminars on the problem of children of labor migrants in 2005-2007, social and school psychologists, social workers, we consider that it is necessary to introduce the third motivational criterion of readiness for work with such children. The problems in the minds and motivation of the pedagogical staff that we found out during our work in recent years are the following: children of internally displaced persons had adapted earlier than adults and had less problems, than adults. Unfortunately, the pedagogical staff do not know how to deal with complicated and serious problems of such children, so they pretend that they do not notice those problems. Teachers do not want to know about the rights of migrant children because such knowledge is an extra responsibility for them. Pedagogical staff and social workers changed their attitude towards migrant children after the workshops on tolerance to internally displaced persons (due to the project in Berdyansk). Teachers expressed such ideas while summarizing the results of the workshops: they understood what the children have come through and how they do live now, so they treat them better, want to help them to return their childhood and make their adaptation easier. The attitude of pedagogical staff to the rights of the child as a basis for interaction in the interests of the children and their rights was changed, after the workshops of "La Strada". Now, that is stated in the concept of the New Ukrainian School. Therefore, the such a criterion for an advanced training course is considered compulsory along with professional cognitive and operational competences. We should underline that the proposed workshop program is brand new and does not involve the previous two programmes. It is concerned with the current problems of children. The experience of their development as well as the implementation of their results have been taken into account for the development of a new program for pedagogical staff at the general secondary educational establishments regardless of the region.

We have considered the criteria and indicators of competence for work with children of labor migrants at 3 levels – high, medium, low. High level characterizes completeness of knowledge and skills development, while medium level – incomplete knowledge and partially developed skills, and low level shows lack of knowledge and skills to work with children of migrant workers.

Motivational criterion of readiness we determined by the attitude of pedagogical staff to the children of labour migrants: positive, neutral, negative. Positive attitude is characterized by the wish to help the child and to treat him or her as a subject of interaction with pedagogical staff at the general secondary educational establishments. The neutral attitude is characterized by treating a child as an object of pedagogical influence. The negative attitude is characterized by treating a child as a victim. The basis for the selection of such indicators is child-centrism and the rights of the child. The attitude itself determines the warmth of the relationship with the child, while the motives indicate the cause for the work. In our case, work is a job and it must be done. But this work can be done with different attitudes. That is why attitude is the main indicator of motivational criterion of the readiness of pedagogical staff to work with children of labour migrants at the general secondary educational establishments.

In order to evaluate the effectiveness of mastering the content of the workshop on the problem, we developed a self-assessment questionnaire for the teaching staff. Let us consider its contents.

Dear participants!

Thank you for taking the time to participate in this study. The survey is conducted in order to identify the impact of the workshop on your professional competence to carry out psychological, social-pedagogical and educational work with the children of labour migrant at the modern general secondary educational establishments.

1. Please name your position at work _____.

2. Do you have experience of working with migrant children? (choose one of the answers): a) yes; b) no; c) some.

3. Are you familiar with the problems of labour migrant's children? (choose one of the answers): a) yes; b) no; c) a little.

4. Do you know how to conduct educational work with the children of labour migrants? (choose one of the answers): a) yes; b) no; c) on certain issues.

5. Do you know how a social teacher works with children from labour migrant families? (choose one of the answers): a) yes; b) no; c) a little.

6. Do you know what kind of work a psychologist does with the children of labour migrant?

7. Do you know about such methods of developing the tolerance and culture as living libraries, living books, tolerance camps, interactive educational classes, etc.: a) yes; b) no; c) a little.

8. Do you know the theoretical background of work with children from labour migrant families? (choose one of the answers): a) yes; b) no; c) a little.

9. Do you know what is a recovering practice at school? (choose one of the answers): a) yes; b) no; c) a little.

10. Do you know how to mediate at the general secondary educational establishments? (choose one of the answers): a) yes; b) no; c) a little.

11. Do you know any method of working with parents and the social environment of labour migrants' children (choose one of the answers): a) yes; b) no.

12. Do you know how to assess child's needs? (choose one of the answers): a) yes; b) no; c) a little.

13. What is your attitude towards labour migrants' children? (choose one of the answers): a) as to victims; b) as to the subjects of pedagogical and psychological work; c) as to the subjects of pedagogical influence.

14. Do you know about the impact of military conflict on children's behavior and psyche? a) yes; b) no; c) a little.

15. Can you solve the problems with children at the higher educational establishments? a) yes; b) no; c) sometimes.

16. Do you know about the possibilities of social services in overcoming the problems of children from labour migrant families? A) yes: b) no; c) a little.

17. Do you know how to overcome stereotypes about internally displaced persons' children and labour migrants' children at school environment? A) yes: b) no; c) a little.

This questionnaire was conducted among 25 correspondence students of the Institute of Postgraduate Education (IPE) of H. S. Skovoroda Kharkiv National Pedagogical University (H. S. Skovoroda KhNPU), who studied the Master's program "Management of the educational institution". A cluster sample was applied. The questionnaire was conducted in May 2019.

We found out in the course of the study that while developing an educational program for the further training of the teaching staff the following issues should be taken into account:

a) a set of scientific approaches, because none of scientific approaches solves the problem, as it should be considered in social, pedagogical, legal, and psychological aspects;

b) the theoretical background of the program content are scientific approaches at different levels, that is why the problem is not only pedagogical. It requires knowledge from different fields of knowledge and interaction of pedagogical and social staff at the GSEE and community;

c) taking into account the ways of problem-solving the set of approaches to develop the content of the program should involve the following scientific approaches:

- philosophical: child-centered, epistemological, pragmatic, family-centered.
- general scientific: systemic, synergetic, critical, political, activity-based, axiological, historical.
- specifically scientific: legal (human rights theory, human development theory, family law, administrative law, social security law, civil law, approaches to human rights protection); social work (crisis intervention, help for self-assistance, resource-based, diagnostic, client-oriented and problem-oriented approaches); social pedagogy (theories of socialization, environmental, social and educational, personal, family-centered approaches to social and pedagogical activity); psychological (genetic, structural-functional, dynamic directions of psychological theories); public administration (regional, institutional and state approaches).
- pedagogical approaches: androgynous, competence-based, personal-oriented approaches, pedagogical support, pedagogy of non-violence, friendly approach, theories of educational content.

In order to substantiate the content of the program of the new course and to confirm its relevance, we conducted a survey of pedagogical staff on the developed questionnaire. The results of the questionnaire survey of pedagogical staff of the GSEE are shown in Table 1.

Table 1. Level of professional readiness criteria (25 people).

	Cognitive criterion	**Operational criterion**	**Motivational criterion**
High level	1 / 4%	0	5 / 20%
Medium level	13/ 52%	9/36%	12/ 48%
Low level	11/44%	16/64%	8/32 %

These data confirm that in general the level of professional readiness of pedagogical workers to work with children of labor migrants at the GSEE is low, in particular an average level of teacher's attitude is observed according to the motivational criterion (emphasis on the rights of the child and child-centrism). As to cognitive criterion, there is almost no complete knowledge as to the work with children of labour migrant and their social environment. Operational criterion proves that more than half of the trainees do not have working skills. Such results prove the relevance of the development of the above-mentioned course for advanced training, the correctness of our considerations on the problem.

All these approaches have allowed us to develop the content of a regional educational program to improve the

teaching staff training to their work with the labour migrants' children and their immediate social environment. We have used the methods of synthesis, generalization, concretization, and modeling. So, let us reveal the programm contents.

In the explanatory letter it is stated that the course is aimed to assist the teaching staff at the GSEE in organizing better conditions for exercising the right to education for labour migrants' children. It characterizes the concept of "labour migrants' children", their categories and problems of each of them, common and different in the problems and needs of children. The concept of parental responsibility, parenthood, rights and responsibilities of parents, the concept of the closest social environment of children and its ability to represent and protect the rights of children, make decisions about children are also disclosed. The experience of education, upbringing and socialization of labour migrants' children at the GSEE in Ukraine as well as abroad is generalized. The course reveals the basics of the interaction of the teaching staff of the GSEE with one another, the interaction of the GSEE with community institutions in the interests of children, with the closest social environment of children. The rights and obligations of the parties in creating the conditions for the realization of the rights of children, their successful socialization, education, upbringing and development are identified. The ways of solving the problem in the GSEE through schools, child-friendly schools, school social-psychological-pedagogical services, pedagogy of non-violence, school services of understanding, work of class leaders. The necessity of mastering this training course for the teaching staff "The work of the general secondary education establishments teaching staff with the children of labour migrants and their closest social environment" is caused by the need to develop the professional competences of teachers to work with labour migrants' children and their closest social workers.

The purpose of the teaching staff further training in the GSEE (teachers, social teaching staff, psychologists) is developing their professional competence; deepening knowledge about the education, socialization and development of labour migrants' children in the new environment; getting acquainted with the modern ways of exercising their rights in the GSEE, interacting with their immediate social environment for the benefit of children. The objectives of the course "The work of the general secondary education establishments teaching staff with labour migrants' children and their closest social environment" are defined as follows: to increase their professional competence, to form the new pedagogical thinking, teaching staff readiness to create various social, pedagogical, legal conditions of the rights for the education of labour migrants' children, including through interaction with their social environment.

The program consists of three modules: "Problems of labour migrants' children", "System of work in the GSEE with labour migrants' children", "Teaching methodology of work at the GSEE with labour migrants' children". The educational-thematic plan of the program is designed for 30 hours of the full-time distance learning: 10 hours – full-time education; 20 hours – self-study (correspondence course).

The topics of the module "Problems of labour migrants' children" are designed for assimilation of complicated problems of labour migrants' children and their families by the teaching staff: psychological, pedagogical, social-pedagogical, social, legal, medical, economic, communication between them; typical problems of labour migrants' children of different ages, depending on the reasons of parental migration: developmental problems, problems of socialization, problems of education, problems of communication and behavior, formulation of life prospects and self-determination, problems of education, formation of model of family life. Understanding the immediate social environment of the child, its structure, opportunities to communicate with him. It is important to form teaching staff with an empathic attitude towards migrants' children, positive motivation to work with their social environment, treat parents of children as those who fulfill their parental responsibilities as loving, strengthen family ties, parent-child relationships.

The second module "System of work in the general secondary educational establishments with labour migrants' children", the normative and theoretical framework of teaching staff interaction with the children, their families, immediate social environment, the ideology of such interaction (the rights of the child, their protection and creation of conditions for realization of rights, crisis intervention, attachment theory, etc.) should be disclosed.

The module "Teaching methodology of work in the general secondary educational establishments with labour migrants' children" reveals the methodology of work of the school psychologist, social teacher, class leader with labour migrants' children. The role of school administration in work with such children, multidisciplinary school team in work with them, specialized school services, which are friendly with children, school services of understanding, pedagogy of nonviolence, features of patriotic and national education, orientation with such children.

So, lets discover the content of the proposed educational program "The work of the general secondary education establishments teaching staff with labour migrants' children and their closest social environment" in modules and topics:

Module 1. "Problems of labour migrants' children".

Topic 1.1. Problems of labour migrants' children.

Problems of labour migrants' children: psychological, legal, pedagogical, social, social and pedagogical, medical, economic, connection between them. Typical problems of development, education, age problems, problems of socialization of labour migrants' children, problems of communication, behavior, formation of model of family life and upbringing, life prospects, etc.

Topic 1.2. The concept of the immediate family environment of labour migrants' children.

Parents of children: their rights and responsibilities, responsibility for children. The closest social environment of labour migrants' children, their

composition, role in child care and upbringing, opportunities and rights, connection with them.

Topic 1.3. The labour migrants' child as an object and subject of pedagogical activity.

The labour migrants' children at the general secondary educational establishments. Problems of their detection in the GSEE and formation of trust in pedagogical workers. The role of social educator, classroom leader, classmate, school psychologist, GSEE administration in working with such children, their opportunities and job responsibilities

Module 2. "The system of work with labour migrants' children at the GSEE".

Topic 2.1. Legal framework for the work of teaching staff with the labour migrants' children at the GSEE.

Legislation of child protection, education, secondary education, family code of Ukraine, Declaration of School Safety. The subjects and objects of children's rights protection, the right of the child to education. Parents' responsibility for children. Rights and opportunities for communication with the child's immediate social environment.

Topic 2.2. Theoretical foundations of the teaching staff work with the labour migrants' children at the GSEE.

Theory of human rights and human development, child-centrism, family- centrism, systematic work with labour migrants' children attachment theory, family development theory, resource approach, environmental approach, participatory theory, community work.

Topic 2.3. The system of work with labour migrants' children at the GSEE.

The Ministry's of education orders about work with labour migrants' children at the GSEE. Registration children into school records and systematic work with them by social educators and school psychologists, administration.

Module 3. "Methods of work with labour migrants' children at the GSEE".

Topic 3.1. Work with the child's immediate social environment and the possibility of indirect work with parents of children.

The multidisciplinary team work with the labour migrants' children and their immediate social environment. Rights and responsibilities of pedagogical and social workers, interaction of community services about children's rights.

Topic 3.2. Organization of the work with labour migrants' children at the GSEE.

School social psychological and pedagogical service. Understanding Service. Pedagogy of non-violence. Child-friendly schools. Countering bulling against labour migrants' children.

Topic 3.3. Creating conditions for realization the right for education of labour migrants' children at the GSEE.

Features of patriotic, national and labor education of labour migrants' children. Assisting children in vocational guidance. Assistance in learning and stimulation, motivation of children to education. Economic education of children. "Self-help assistance" in working with children of labour migrants' children to determine life prospects and their realization.

Taking into account the age and the level of teaching staff training, we recommend to use the following teaching methods: 1) the nature of cognitive activity: explanatory, illustrative, reproductive, problematic presentation, partially search, research; 2) by sources of knowledge: information, illustration, demonstration, discussions, learning from experiences, situations, situation analysis, brainstorming. It is advisable to use such forms of study as work in microgroups, practical classes, training classes.

3 The results of the research

The structure of the course "The work of the general secondary education establishments teaching staff with the labour migrants' children and their closest social environment" is shown in the table 2.

Table 2. The structure of the course "The work of the general secondary education establishments teaching staff with the labour migrants' children and their closest social environment".

Module themes	**Classroom hours**		**Individual work**
	lectures	tutorials	
Module 1. Problems of labour migrants' children			
Topic 1.1. Problems of labour migrants' children	1	–	–
Topic 1.2. The concept of the immediate family environment of labour migrants' children	1	–	4
Topic 1.3. The labour migrants' child as an object and subject of pedagogical activity.	1	1	2
Module 2. The system of work with labour migrants' children at the GSEE			
Topic 2.1. Legal framework for the work of teaching staff with the labour migrants' children at the GSEE	0,5	–	2
Topic 2.2. Theoretical background of the teaching staff work with the labour migrants' children at the GSEE	1	–	4
Topic 2.3. The system of work with labour migrants' children at the GSEE	0,5	1	–
Module 3. Methods of work with labour migrants' children at the GSEE			
Topic 3.1 Work with the child's immediate social environment and the possibility of indirect work with parents of children	0,5	–	2
Topic 3.2. Organization of the work with labour migrants' children at the GSEE	1	1	4
Topic 3.3. Creating conditions for realization the right for education of labour migrants' children at the GSEE	0,5	–	4
Total	7	3	20

Taking into account the trainees' age and level of preparation, we recommend to use the following teaching methods: 1) by the nature of cognitive activity: explanatory, illustrative, reproductive, problematic presentation, partially searching, researching; 2) by the sources of knowledge: informative, illustrating, demonstrating, discussing, learning from experiences, situational, situation analysis, brainstorming. It is reasonable to use such forms of study as work in microgroups, practical classes, and training sessions.

From the results of the study presented in the article it is obvious that the teaching staff at the GSEE do not work in a multidisciplinary team today, this idea is promoted only at the level of the children's ombudsman of Ukraine, each educator in his/her position is a leader and seeks through inherent teacher-training humanism to solve all the problems of children themselves, without even having the necessary competences, only because of his/her natural kindness and sincere desire to help children. It usually causes professional burnout, frustration, overwork, stress and even illness. Therefore, teaching to teamwork at the GSEE and community on the background of regulatory documents, theoretical foundations, interaction between teaching staff and their integration into a certain structure would better help children, teach how to solve their problems comprehensively and systematically, save teachers' resources. Besides, knowledge of the theoretical background of working with the families of labour migrants' children allows them to provide targeted assistance to children and their immediate social environment, rather than simply to show kindness where professional help is needed. So, the proposed educational course will be helpful for solving the problems of labour migrants' children and their immediate environment, as well as dysfunctional and distant families, incomplete families, foster families, and social orphans.

4 Conclusion

It was proved that the problem of the teaching staff work with labour migrants' children at the general secondary educational establishments is urgent in order to overcome poorness and poverty in Ukraine. The problem has new features in connection with the military conflict in Ukraine, visa-free regime with the European Union for Ukrainians and is solved by implementation of work with labour migants' children and their close environment by improving the content of teachers' further training program. It was discovered that the aim of teaching staff' training is the professional readiness to work with children of labour migrants at the GSEE. It is characterized by cognitive, operational, motivational criteria. The level of development is characterized as high, medium, and low. It was distinguished that the level of teachers' readiness to work with labour migrants' children is typically low according to cognitive and operational criteria, and medium according to motivational criterion. A set of the following scientific approaches at different levels for updating the content of the regional educational program for teaching staff further training for their work at multidisciplinary team was developed: 1) philosophical; 2) general scientific; 3) specifically scientific; 4) pedagogical. On this basis we have developed a new educational program to improve the skills of the teaching staff for work with the labour migrants' children and their social environment which consist of 3 modules ("Problems of labour migrants' children", "The system of work with labour migrants' children at the GSEE", "Methods of work with labour migrants' children at the GSEE"). The program includes 30 hours of training, and recommendations on the program's teaching, which correspond to its purposes, methods and appropriate forms for adults training.

The prospects for further research are in the field of testing and experimental verification of the programs.

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Motivation of modern Ukrainian teachers' professional activities: generation archetypes

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Abstract. The article gives an analysis of data of an All-Ukrainian Monitoring Survey conducted by the Ukrainian Educational Research Association using TALIS methodology among secondary school teachers to determine generation differences of professional activity motivation. According to the generation theory of W. Strauss and N. Howe, we implement the new variable "generation" into the empirical data in order to divide the selected cluster into homogeneous groups of representatives of the Silent Generation, Baby boomers, Generations X, Y, and Z. To find the motivation for professional activity, we used the methodological approach of J. Barbuto and R. Scholl. Appealing to the concepts of V. Rozanov, Iu. Kuliutkin and V. Bezdukhov, the authors of the article attempted to determine motivation methods for professional activity for all generations of teachers.

Introduction

The reform of the national school education system provides its transformation in accordance with the needs of society and socio-economic opportunities of providing the functioning of the system in a certain period. Key figures of the changes are certainly teachers. Providing education quality starts with the formation of teachers' motivated professional activity because they must adjust themselves to dynamically changing socio-economic and sociocultural conditions of education. They also must master innovative education technology, enrich, re-estimate and produce new knowledge, determine their place in society, assume new social roles, and be qualified and professionally mobile.

In the opinion of V. Rozanov [14] the efficiency of motivation control depends on the possibility to implement the learner-centered approach, namely on the knowledge of needs and individual characteristics of employees, understanding of their goals, wishes and ambitions, usage of a wide number of encouraging methods in communication with them including kindness, tolerance, and ethics. By forming teachers' motivation, school headmasters have an opportunity to reach the goal of the school functioning, form its reputation and increase the working performance of the teaching staff in general.

Developing the concept of educational management L. Kalinina, L. Karamushka, T. Sorochan, R. Shyian [2] appeal to the opinion that every teacher has his/her own relatively stable system of professional activity motivation, depending on their worldview, orientation, traits of character, self-awareness, life and professional experience. Therefore, motivation control should include the formation of favorable conditions to activate their professional activity.

The relationship between teaching activity motivation and values is one of the most complex and interesting problems for education researchers. V. Yadov [3] was the first to study values as an independent component of teaching activity, determining them as the axis of consciousness of the teacher, around which his/her thoughts and feelings are grouped. Taking into account the fact that the hierarchy of these values influences the expansion of vital interests, it is the professional values of teachers' orientation that determine the degree of their activity, according to the highest needs for self-expression and self-improvement. However, I. Bekh claims that some teachers have anti-innovation barriers. They think and act stereotypically because they used toper form a significantly narrower range of tasks. Their attitude toward changes is not sensible enough and the internal motivation for their professional activity is rather low [4]. In the first place, the question here is in the relationship between values and motivation for professional activities of teachers belonging to different age groups.

Nowadays under the conditions of a systemic crisis in the country teachers-enthusiasts, whose choice of profession is motivated by high social significance must be adaptive, dynamic, ready for all kinds of innovations to be able to avoid the situations of functional illiteracy and professional incompetence. Within the scientific approach of Iu. Kuliutkin, V. Bezdukhov [5] propose to consider the combination of teacher experience and self-reflection as the leading

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factors in the development of the education system. This approach emphasizes that knowledge of the leading motivation of professional activity and the hierarchy of personal values is an important but not sufficient condition to choose the best ways to encourage the teachers. Of extreme importance is how they perceive and evaluate certain situations and what they consider as expected of them.

In this sense, the need to determine the value differences among the representatives of various generations of teachers, the value points of their identification in order to avoid possible conflicts is relevant. In our opinion, that is why identification and analysis of differences in value systems, professional activity motivation and readiness for self-expression, self-improvement of representatives of different generations of teachers can define the range of possible problems on the way towards the formation of the new Ukrainian school and develop practical recommendations to improve the situation.

Results and discussion

According to the theory of W. Strauss, N. Howe [6] the values of representatives of different generations determined by the socio-economic conditions under which the personality and worldview of the generation representatives developed. Thus, the authors distinguishes among others the Silent Generation (people who were born in 1925-1942), the generation of Baby boomers (1943-1960), Generation X or the 13th Generation (1961-1981), Generation Y or Millennially (1982-2004), Generation Z or Homeland Generation (since 2005). Indicated periods are relative. A basic duration of influence and transformation is about 20 years, which corresponds to socially and biologically determined phases of human life. Created on the ground of archetypes, specific images always correlate with the dominant cultural program of a certain period producing them. Generations of the same archetype are united by the specifics of the historical location, initial experience and general characteristics at the individual and system levels as and the general configuration of the life.

W. Strauss, N. Howe paid special attention to the archetypes of generations (prophet, nomad, hero, artist) formed according to the "crisis-high-awakening-unraveling" cycles in the development of society [6]. The generation of prophets is born during the end of the crisis, thus they are characterized by morality and eccentricity. Born in the high cycle, the generation of nomads is distinguished by its rebelliousness, critical appraisal of the predecessors' activities, and pragmatic leadership. Heroes are born in the era of unraveling; they are characterizing by optimism, energy, individual pragmatism, and self-reliance. Then artists are born who get under hyper protection of their own predecessors. They are characterizing by individualism, adaptability, and aesthetics. Generations born in the eras of crisis and awakening are more active, independent, and become the driving force of historical events. Unlike them, those formed in the high and unraveling periods are considered as recessive, more adaptive to living conditions created by previous generations.

M. Titma [7] and B. Urlanis [8] carried out thorough researches of the generations' differences focused on the study of self-identification and values. Y. Levada investigated the characteristics of the age groups development and proved that the "generation gap" represents a split in the system of values, which takes place under certain circumstances of socio-historical development [9]. Studying the social dynamics of post-Soviet societies, he concluded that the communities are characterized by inertness of social attitudes and values. It is demonstrated in consciousness change between generations and stereotyped behavior of the majority of representatives of these societies. According to the researcher, these trends considerably slow down the implementation of any reforms.

Analyzing the mentality types of different generations' representatives, V. Pischik highlighted their dominant values. Thus, in her opinion, representatives of the Silent Generation are characterized by loyalty, patience, honesty, and categoricalness, while Baby boomers are distinguished by optimism, collectivism, family orientation, and communication skills. Generation X is characterized by readiness to sacrifice, aesthetics of life, orientation towards common well-being, sociability, technical literacy, informality of views, heterogeneity, emotionality, and representatives of Generation Y are known by their innovative activity, naivety, hedonism, and the desire for quick reward. In contrast to its predecessors, Generation Z is self-centered and inattentive, but tolerant and fair at the same time, with its inherent "clip" thinking and short communications [10].

L. Novikova in her works adapted the theory of the generations of W. Strauss and N. Howe to Ukrainian reality appealing to the central events that occurred during the years of birth of the generations' representatives. She distinguished such generations as those who were born before the Second World War (1930-1939) (70-year-olds); 'post-war generation' (1950-1959) (50-year-olds); generation of the period of 'socialism stagnation' (1970–1979) (30-year-olds); generation of 'independence' (1989-1993) (20-year-olds) [1]. Analyzing the results of the World Values Survey 2011 (WVS) the author concluded that among other generations, the youngest generation born at the turning point of the Soviet era is especially noticeable because its representatives are characterized by a strongly marked intergenerational shift. Representatives of all four generations are united by the dominance of materialistic values, in particular, existential security and external authority. Unlike its predecessors, the generation of independence focuses on the development of their own abilities and competencies, considering them as a factor of well-being. Post materialistic values are prevalent for the group. Self-expression is less important for the Silent

Generation than it is for Baby boomers and Generation X.

Mentioning the archetypes of generations demonstrated in the motivation of the teachers' professional activities, we should note the fact that motivation is very closely related to values and value orientations as consciously chosen guidelines for activity. Values are formed in the process of personal development and active work; they also enable motivation control. Teacher performance is not determined by one specific motive; it is polymotivational in its nature. For the teacher activity there are internal (reward, approval, prestige, career growth, etc.) and external motivations (interest in professional growth, result orientation, self-development, etc.). Value motivation for an individual in education establishment acts both as an effective tool in staff management and as an instrument for achieving the educational process goals. At the present stage of development of the general secondary education with its focus on innovation activity, the motive for self-improvement and self-actualization as readiness for activity under new conditions becomes especially important.

To determine the peculiarities of the motivation for professional activity, readiness for self-expression and self-improvement of representatives of different generations of teachers, we carried out an analysis of the data of the All-Ukrainian Monitoring Survey. The Survey was conducted in February-August 2017 by the Ukrainian Educational Research Association using TALIS methodology among the secondary school teachers. The research sample consisted of 3,600 teachers in 5-9 grades of 201 Ukrainian secondary schools [11].

In an open database formed on the results of the survey and presented on the official website of the Ukrainian Association of Educational Researchers, among other personal data about survey participants, their age was indicated. It let us divide the sample into homotypic and homogeneous groups of representatives of the Silent Generation, Generations X, Y, and Z through the introduction of the additional variable. It is similar to the interpretation of the theory of the generations of W. Strauss and N. Howe (the groups account for 0.4%, 26.3%, 54.2%, 19.0%, and 2% of the total sample size correspondingly) [6]. As for the peculiarities of professional activity, we should note that representatives of the Silent Generation and Baby boomers in most cases are completing their working career and retiring, while representatives of Generation X are at their highest position in profession, and representatives of Generations Z and Y are just beginning their career.

To determine the generation differences in the teachers' motivation for professional activity we used the methodological approach of J. Barbuto and R. Skoll and singled out five groups of motives. They are internal motives that focus on the process, self-improvement and self-realization; external motives that include reward and approval of others; integrative motives that coordinate the goals of an individual employee with the goals of the whole staff [12].

The first important group of motives includes the system of leading interests and attitudes, the social orientation of a teacher as a representative of society and a performer of an important social task, his/her readiness for professional activity. Considering the importance of their profession in society, most representatives of the Silent Generation expressed themselves quite critically, as 85.5% of them disagree with the fact that teaching is valued in the modern Ukrainian society. Nevertheless, the others, in particular the teachers of Generations Y and Z are more optimistic as correspondingly 42.2% and 57.2% of them believe that the teacher's job is socially important.

However, despite the fact that the majority of respondents like to work at school, there is a certain ambiguity in their thoughts, namely, among representatives of the youngest group because they are the most dissatisfied with their choice of profession. On the other hand, the predominance of the conscious choice of the profession is also confirmed by the fact that 87.4 % of respondents agree fully or partially with the statement that the advantages of teaching career outweigh disadvantages. Indeed, teachers can be compared with altruists who refuse public recognition consciously in favour of favourite occupation, because for most of them it is not just a profession, but also a way of life (see tab. 1).

Table 1. Distribution of answers to the question 'Do you agree with the statement that teacher is appreciated in the society?' (%, of the total number of respondents).

	Silent Generation	**Baby boomers**	**Generation X**	**Generations Y**	**Generations Z**
In my opinion, teacher as a job is appreciated in the world					
Completely disagree	28.6	14.9	16.4	12.9	14.3
Disagree	57.1	51.3	56.8	44.3	28.6
Agree	14.3	25.4	22.3	54.7	42.9
Completely agree	0	6.6	4.5	8.1	14.3
If I had to choose, I would choose teaching again					
Completely disagree	0	2.3	2.9	5.5	0
Disagree	14.3	7.8	16.3	20.2	28.6
Agree	50.0	50.6	57.1	58.1	57.1
Completely agree	35.7	39.3	23.6	16.2	14.3
Advantages of teaching outweigh disadvantages					
Completely disagree	7.1	1.7	1.7	2.2	0
Disagree	0	8.1	13.5	14.9	14.3
Agree	78.6	68.5	71.2	69.07	71.4
Completely agree	14.3	21.7	13.7	13.3	14.3
I like working at this school					
Completely disagree	0	1.7	1.3	1.9	0
Disagree	7.1	3.6	4.4	5.7	0
Agree	57.1	45.9	56.8	58.1	28.6
Completely agree	35.7	48.7	37.5	43.7	71.4

It is quite logical that certain doubts about the level of readiness for professional activities are more peculiar to young teachers, primarily due to the lack of experience (see table 2). Since they consider themselves prepared in terms of content filling of

subjects, but have doubts about the methods of teaching and the progress of teaching practice. For teachers of Generations X, Y and Z, there is a positive trend to age reducing, which can evidence qualitative changes in the process of training specialists in higher education institutions, increasing the effectiveness of professional development activities etc. However, these assumptions require further studying.

Table 2. Distribution of answers to the question 'How prepared are you to the points in your teaching given below?' (%, of the total number of respondents).

	Silent Generation	Baby boomers	Generation X	Generations Y	Generations Z
Content filling of subjects that I teach					
Completely unprepared	0	7.0	6.7	3.7	0
Prepared to some extent	0	1.6	1.5	4.4	0
Well prepared	78.6	51.0	57.5	62.2	71.4
Very well prepared	21.4	40.5	34.2	29.7	28.6
Methods of teaching subjects that I teach					
Completely unprepared	0	7.0	6.3	3.2	14.3
Prepared to some extent	0	2.3	3.0	4.7	0
Well prepared	78.6	52.2	59.9	68.6	85.7
Very well prepared	21.4	38.4	30.8	23.4	0
Teaching practice of subjects that I teach					
Completely unprepared	0	7.0	6.5	3.1	14.3
Prepared to some extent	0	2.1	3.5	5.9	0
Well prepared	78.6	49.7	55.1	64.7	71.4
Very well prepared	0	7.0	6.5	3.1	14.3

Self-improvement and self-realization are important determinants of teacher's professional development. They ensure the expansion of his/her opportunities, interests, and the formation of individuality.

Readiness for self-improvement appears only when a teacher is internally free from any fears, failures, critically evaluates his/her abilities, opportunities, and is aware of the need for change. Silent Generation should urgently improve their skills in working with information and computer technologies. Generation Z has little experience in assessing student behavior and class guidance. The younger the generation of teachers is, the more they feel the need for professional development in the field of individual learning, working with students with special needs. The archaism of the professional activity of the Silent Generation is a biased attitude towards the possibility of teaching children with physical and mental health disabilities together with healthy children (see table 3). However, they actively express their readiness for self-improvement, as well as representatives of other age groups.

There are no particular differences in age preferences among organizational forms and methods of self-improvement and self-realization, except the tendency of Generation Z representatives to borrow advanced teaching experience of older colleagues in such forms as scientific, practical teaching conferences and seminars, reference/review visits to enterprises, public and non-governmental establishments. The younger teachers are, the less they need to participate in qualification programs and the more desirable an active practice of sharing experiences through mentoring and/or engaging in learning, participating in the activities of professional associations is.

Table 3. Distribution of answers to the question 'How do you feel the need for professional development in each of the following areas?' (%, of the total number of respondents).

	Silent Generation	Baby boomers	Generation X	Generations Y	Generations Z
Awareness of the place of the subject in the general training program					
Not necessary	35.7	58.9	46.6	48.7	50.0
Little necessary	28.6	21.2	28.7	29.0	50.0
Necessary	28.6	16.1	20.3	19.8	0
Very necessary	7.1	3.8	4.4	2.5	0
Students assessment and assessment approaches					
Not necessary	35.7	52.8	40.1	36.5	28.6
Little necessary	14.3	25.5	32.6	34.8	57.1
Necessary	42.9	17.6	22.8	24.1	0
Very necessary	7.1	4.1	4.5	4.6	14.3
Information and computer technology skills					
Not necessary	14.3	10.4	15.6	34.5	50
Little necessary	7.1	27.3	32.1	33.6	50
Necessary	42.9	44.8	36.2	23.9	0
Very necessary	35.7	17.4	16.0	8.1	0
Students behavior and class guidance					
Not necessary	42.9	46.9	34.9	23.1	0
Little necessary	21.4	29.3	32.7	37.9	57.1
Necessary	28.6	20.1	25.5	30.1	42.9
Very necessary	7.1	3.8	6.8	8.9	0
Individual studying approaches					
Not necessary	64.3	39.5	26.8	23.6	28.6
Little necessary	14.3	32.2	37.7	40.8	28.6
Necessary	21.4	24.3	31.0	30.1	28.6
Very necessary	0	4.0	4.5	5.4	14.3
Teaching students with special needs					
Not necessary	76.9	47.6	35.8	36.8	14.3
Little necessary	7.7	22.8	27.3	25.2	57.1
Necessary	15.4	25.2	30.2	30.9	0
Very necessary	0	4.4	6.7	7.1	28.6
New technologies in the workplace					
Not necessary	21.4	9.7	8.9	14.3	14.3
Little necessary	7.1	27.9	26.2	26.4	42.9
Necessary	64.3	48.5	45.7	42.4	28.6
Very necessary	21.4	9.7	8.9	14.3	14.3

The high level of self-motivation confirmed by the fact that almost half of the representatives of the Silent Generation, Generation Z and every fourth representative of the Baby boomers, Generations X and Y are willing to pay for participating in advanced training activities (see table 4).

Analyzing the existing obstacles to self-improvement and self-realization, determined by the teachers' estimates, it is noted that the index of the balance of assessments is indicative, which is defined as the difference in percent of positive and negative response options multiplied by a factor of 1 and 0.5 respectively.

Table 4. Distribution of answers to the question 'What financial basis did your professional development events in which you participated during the last year have?' (%, of the total number of respondents).

	Silent Generation	Baby boomers	Generation X	Generations Y	Generations Z
Unpaid	55.6	79.5	73.5	76.9	50.0
Part-paid	22.2	14.0	18.6	16.1	16.7
Full-paid	22.2	6.4	8.0	7.0	33.3

Table 5. Distribution of answers to the question 'How do you agree or disagree with the below mentioned obstacles to your professional development?' (%, of the total number of respondents).

	Silent Generation	Baby boomers	Generation X	Generations Y	Generations Z
Professional development is too expensive / financially out of reach					
Completely disagree	21.4	29.9	23.9	20.0	42.9
Disagree	50.0	51.4	53.3	51.8	57.1
Agree	28.6	17.5	19.7	25.5	0
Completely agree	0	1.2	3.1	2.7	0
Assessment balance	-32.1	-45.7	-37.6	-30.5	-71.5
No employer support					
Completely disagree	71.4	37.0	30.4	30.3	42.9
Disagree	21.4	50.4	51.7	53.6	57.1
Agree	0	10.7	14.5	12.0	0
Completely agree	7.1	2.0	3.5	4.1	104.3
Assessment balance	-75.0	-54.9	-45.5	47.0	-71.5
Professional development programs are implemented during my working hours					
Completely disagree	23.1	16.3	11.5	10.9	42.9
Disagree	0	31.7	36.1	32.7	14.3
Agree	61.5	43.3	45.9	48.5	42.9
Completely agree	15.4	8.8	6.5	7.9	0
Assessment balance	23.1	-1.7	-0.1	4.9	-28.6
I don't have time because of family obligations					
Completely disagree	50.0	41.4	28.0	28.1	57.1
Disagree	50.0	51.6	57.8	56.3	42.9
Agree	0	5.5	12.7	14.3	0
Completely agree	0	1.5	1.5	1.3	0
Assessment balance	-75.0	-63.0	-49.1	47.8	-78.6
No corresponding professional development programs					
Completely disagree	28.6	31.9	24.4	20.8	28.6
Disagree	50.0	53.1	55.7	56.6	57.1
Agree	21.4	13.4	17.0	19.9	0
Completely agree	0	1.6	2.8	2.7	14.3
Assessment balance	-42.9	-50.2	-41.0	-36.5	-42.9
No reward for participating in such events					
Completely disagree	28.6	19.3	12.2	12.2	28,6
Disagree	28.6	41.2	34.9	32.6	28,6
Agree	21.4	30.5	39.0	40.9	28,6
Completely agree	21.4	9.0	13.9	14.3	14,3
Assessment balance	-10.8	-15.7	3.8	6.3	-14,3

For representatives of the Silent Generation, the biggest obstacles for professional development are the inconsistency of their time (most professional development programs are implemented during my working hours), which leads to disruption of the educational process, and the lack of stimulation of participation in such events by school authorities. The younger the teachers are, the less they care about the fact that professional development events are carried out during working hours. For representatives of Generations X and Y a more significant obstacle to self-improvement than for others is the lack of reward for participation in such events, as well as the lack of time because of family obligations (see table 5).

As for the last group of motives, namely the consistency of the goals of a particular teacher with the goals of the teaching staff, we should note that the majority have the opportunity to participate in school management on a democratic basis. Only the more ambitious representatives of Generations X and Y have some doubts. The majority of respondents also agree that an atmosphere of mutual understanding and mutual assistance prevails at schools where they work (see table 6).

Table 6. Distribution of answers to the question 'How do you agree or disagree with the statements about your school?'

	Silent Generation	Baby boomers	Generation X	Generations Y	Generations Z
The school gives teachers the opportunity to take an active part in making decisions about the school					
Completely disagree	7.1	2.7	3.3	2.4	0
Disagree	0	7.9	15.2	17.6	0
Agree	71.4	66.4	67.6	70.2	71.4
Completely agree	21.4	23.1	14.0	9.9	28.6
There is a common school culture characterized by mutual help and mutual support					
Completely disagree	7.1	1.7	1.9	1.8	0
Disagree	14.3	8.5	9.2	11.8	0
Agree	71.4	63.9	69.5	68.9	100
Completely agree	7.1	26.2	19.5	17.5	0

Among other motives of professional activity, one should pay attention to the motives of having self-profit (material satisfaction and approval from others). Thus, answering the question about how the results of the assessment of professional activity influenced the official recognition by the head teacher and colleagues, all respondents of Generation Z noted positive changes, almost every seventh teacher of Generations X, Y and Baby boomers noted minor changes. In the opinion of half of the respondents, despite the positive assessment of the activity, their success brought no payment rise nor career advancement. However, most teachers think that the results of the assessment increase their self-confidence and work enjoyment, as well as strengthen professional activity motivation. This fact confirms conscious internal motivation for professional activity prevailing in most teachers of Silent Generation and Generation Z, and peculiar to almost half of representatives of Generations X, Y and Baby boomers (see table 7).

Table 7. Distributions of answers to the question 'How do obtained results of your professional activity assessment influence positively the following?' (%, of the total number of respondents).

	Silent Generation	Baby boomers	Generation X	Generations Y	Generations Z
Official recognition by the head teacher and/or colleagues					
No positive changes	0	2.3	3.4	3.8	0
A little bit	15.4	11.2	15.4	12.9	0
Moderately	69.2	40.2	40.4	43.4	83.3
A lot of influence	15.4	46.3	40.8	39.9	16.7
Career development opportunity					
No positive changes	23.1	14.3	12.2	13.0	0
A little bit	46.2	27.3	23.3	21.8	16.7
Moderately	30.8	31.0	36.5	39.0	66.7
A lot of influence	0	27.3	28.0	26.2	16.7
Your self-confidence as a teacher					
No positive changes	7.7	2.2	3.0	2.7	0
A little bit	30.8	9.4	11.3	12.1	16.7
Moderately	46.2	38.3	40.7	37.0	66.7
A lot of influence	15.4	50.2	45.0	48.2	16.7
Your salary and/or premium					
No positive changes	15.4	15.6	20.6	25.0	16.7
A little bit	7.7	27.1	31.8	31.9	16.7
Moderately	61.5	36.2	33.0	30.7	50.0
A lot of influence	15.4	20.2	15.6	12.4	16.7
Your pleasure from work					
No positive changes	7.7	2.9	4.8	6.3	0
A little bit	23.1	10.2	14.8	13.9	0
Moderately	53.8	46.7	48.1	43.5	50.0
A lot of influence	15.4	40.2	32.2	36.3	50.0
Your motivation					
No positive changes	7.7	3.7	5.8	6.9	0
A little bit	30.8	14.1	16.3	10.7	33.3
Moderately	46.2	45.3	45.7	43.6	33.3
A lot of influence	15.4	35.9	32.2	38.8	33.3

Conclusions and generalizations

Summarizing the results, we should note that representatives of the Silent Generation and Baby boomers are completing their professional pass; teachers of Generations X and Y are at their peak of teaching career while Generation Z is taking the first steps in the professional field. Each of these generations has its own archetype manifested in the professional activity motivation. Representatives of Generation Z adapt actively to the conditions of professional activity; young teachers have a certain amount of knowledge but do not have any sufficient practical experience in its application. Teachers of Generation Y have a stable professional activity, formed personal position, awareness of the desire for self-realization, and the desire to improve teaching skills. Most teachers of Generation X have a psychological crisis, connected with the awareness of the contradictions between their desire for self-improvement and the real opportunities of teaching. Baby boomers are characterized by a high level of development of professionally significant qualities, stability in socio-economic terms, self-confidence, and confidence in teaching skills. Teachers of the Silent Generation are distinguished by the combination of biological and professional aging, manifested in the rejection of innovation, the violation of partnership with students and colleagues, and psycho-emotional overstrain.

Compared to others, teachers of Generations X and Y are especially distinguished where the external motivation of professional activity prevails, but the representatives of the Silent Generation, Baby boomers and Generation Z are determined by internal motivation. However, teachers of Generation Y, in their opinion about self-improvement and self-realization, are closer to Generation Z than to Generation X. At the same time, there are positive trends in changes in the culture of self-determination and self-affirmation of representatives of different generations of teachers towards the development of innovative means and forms. In addition, we can see the liberalization of attitudes towards special children, which is of great importance under the conditions of the development of an inclusive component of modern national education.

In the national practice of managing the teaching staff of the school, the adaptation of the main aspects of generations' theory, taking into account the value approach, will make it possible in the long-run to implement effective management in school based on humanistic paradigm. Taking into account the generation differences, we advise to use the following methods of non-material motivation for professional activity within a person-oriented approach towards representatives of different generations. For the representatives of the Silent Generation this means ensuring stable social status, guarantees of social package, respect and reverence by students, parents, colleagues, and school authorities. For Baby boomers, it is the interest in personal development, team cohesion, friendly relations and the desire for innovation. For Generation X this means the prospect of self-realization and career growth, the desire to learn continuously. For Generation Y it is the realization of creative potential, providing opportunities for learning and development. For Generation Z this implies sharing experience, evaluation of individual achievements, as well as the opportunity to receive real-time feedback and participate in the management of an educational institution democratically.

Under the conditions of reforming the secondary education system in Ukraine, the implementation of innovations in school management is impossible without strengthening the role of teachers as subjects of the educational process, forming partnerships between all management subjects, taking into account the specific conditions of the educational process, the number of students and the personnel potential of a particular school. It is necessary to introduce reforms in the education system, predominantly relying on Generation Z, as the part of the teachers' community most open for communication and interaction. Nevertheless, it is also necessary to take into account

the experience of mature generations, since they can teach young people purposefulness and creativity in solving difficult professional tasks.

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Ensuring sustainable development of education of future maritime transport professionals by means of network interaction

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Abstract. The article describes the concept of sustainable development, which is one of the modern trends of scientific research in the 21st century. The analysis of scientific researches has been carried out in the context of the mentioned problem of sustainable development, the tendencies of development of the network interaction theory as factor of sustainable development of maritime education have been transformed into pedagogical practice of maritime higher educational establishments. The main objective of the article is to express the idea that the rapid development of information is the main impetus for the transformation of education, updating its content and forms, methods and technologies, improving the efficiency and accessibility of quality education. The process of network interaction on the example of creating an e-course for foreign students is substantiated. There was considered the possibility of modernizing the training of maritime professionals using modern information technologies (distance technologies, augmented reality and VR). The prospect of network interaction ideas has been proved, which is confirmed by the effectiveness of the introduction of the Moodle e-course for international entrants. It is shown that the students participate in network interaction, create the frame for successful adaptation of international students in Ukraine.

1 Introduction

The twenty-first century has opened risks exacerbation of civilization's unsustainable development, increasing obstacles to disturbance of biosphere equilibrium. According to the UN news, in the first twenty years of the new century 6,457 natural disasters have occurred in the world, affecting more than a third of the world's population [1].

In the era of globalization, there is a significant reorientation of the values of world civilization. The phenomenon of the explosion of digital technologies is resulting in the rapid development of ICT technologies and a diminished focus on the humanitarian, cultural component of human life. This leads to a violation of equilibrium in society. And scientists point to the emergence of a new stage of civilization development – ecological-information civilization [2].

The concept of sustainable development is one of the modern trends of scientific research in the twenty-first century. But due to the lack of a common understanding of the "sustainable development" concept, the unified definition has not yet been created.

In 1987, the UN Commission on Environment and Development identified in the report "Our Common Future" the key idea of sustainable development as a development that meets the needs of the modern generation without sacrificing the ability of future generations to meet their personal needs. The International Maritime Organization (IMO) also reiterated this initiative, emphasizing that adopting this concept can help to increase awareness of the need for sustainable maritime development and to coordinate maritime policy worldwide [3].

Sustainable development is perceived by the international community as a benchmark and a goal of sustainable development for empowerment in addressing environmental and human factors.

The component of sustainable development is network interaction. Maritime education doesn't have any research in this field. Network cooperation is an effective method that allows future maritime specialists to adequately and timely respond to changes that take place, including: globalization and expansion of the international space of industrial enterprises; the need for quick adaptation to constantly changing environment; increased competition at various levels; development of information technology and knowledge economy.

The objective of the article is to show and analyze the practical implementation of network interaction to ensure sustainable development of education of future maritime transport professionals. This will help to

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encourage changes in knowledge, skills, values and attitudes of students and entrants of a maritime higher educational establishment.

2 Key results of research

2.1 Sustainable development concept in scientific discourse

Philosophers give the following definitions of sustainable development: the creative evolution of a system, under which no transformations within the system, no external factors can bring it out of the state of dynamic equilibrium [4]; a form of hope for another "technological breakthrough" that will help to harmonize relations between the man and nature, as well as the transition to the noospheric type of human and nature existence [5]; the term "sustainable development" can be considered identical to the term "co-evolution of the man and the biosphere", which originates in the writings of V. Vernadsky and K. Tsiolkovsky and places emphasis on the environment [4].

Turning to philosophical interpretations allows us to synthesize a new definition of "sustainable development" based on the modern concept of world civilization development. Society is on the verge of the fifth industrial evolution, when the convergence of the man and technology will lead to the emergence of new scientific and ideological approaches with the prospect of development in the third millennium. Development is always about growth, so it is imperative to determine whether such growth is conducive to building a sustainable future in the information society. Formation of a new stage of civilization development must take into account all new forms of transformation of society: global, regional, ecological-informational and informational-virtual as components of noospherogenesis.

It is the approach that will have a synthesizing positive role in creating a common theory of sustainable development [6, 7]. At the UNESCO World Education Conference in Aichi-Nagoya (November 2014), a declaration was adopted calling for urgent action to strengthen education for sustainable development and to expand its reach. As a result, in 2015, world leaders at the UN Headquarters proclaimed 17 Sustainable Development Goals, with 4 goals: ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all.

Scientists create a model of sustainable development at the conceptual-theoretical level, and the next stage is that education itself will shape the sphere of people's consciousness. So, as A. D. Ursul, sustainable development education is not only a prerequisite for achieving sustainable development, but also a priority for it [8].

And future education of sustainable development will have a system-leading character, fulfilling the function of training a person for leading actions in the conditions of global anthropoecological crisis and leaving it on the way to transition to sustainable development. Under the concept of advancing we will understand the process of evolution and advancement for the better.

Modern researchers place intellectual, spiritual and rational-information factors and resources, which have no restrictions unlike material and natural, and are the key to the survival and further development of civilization.

According to scientists, informatization and virtualization of human activity remove virtually all restrictions, all constants and behaviors that accompanied man on the path of civilization, resulting in the loss of landmarks [9]. And education itself can be the engine of change for the formation and greening of consciousness, awareness and international cooperation for the orientation of content and forms of education to our common sustainable future.

The rapid development of information is a major impetus for the transformation of education, updating its content and forms, methods and technologies, improving the efficiency and accessibility of quality education. The transition to the information model of society makes it necessary to become a type of education that expands its scope in the world of educational space, blurs the boundaries and changes the usual norms. At the same time, information flows and actions on a planetary scale can become risk factors and lead to catastrophe. Modern society recognizes that information is the most important strategic resource that is limitless, and the use of information, on the contrary, leads to an increase in the volume of these resources.

But there is a contradiction when society is already immersed in the information age and the consciousness of the majority remains in the time of the industrial era. "Humanity has come to the threshold beyond which new morality, new knowledge, a new mentality, and a new system of values are needed". Authors of [10] forms a clear "environmental imperative": "What was permissible in the past is already unacceptable today".

Therefore, it is imperative to develop such a system of education, where the information culture will foster the development of information awareness, which will make it possible to build a proper cybersecurity system, both state and personal. In the problem of formation of human responsibility for life on the planet, the central issue is the qualitative characteristics of man, which shape the integrity of the outlook of the individual, the development of independent, critical thinking.

It is determining the need to create a new quality of education that will construct new pedagogical tools capable of providing a civilizational transformation, building a world of sustainable development, as the basis of a new outlook and sustainable way of life.

According to the UNECE's Strategy for Education of Sustainable Development, the most important thing is to create competences for self-education and self-identification, work as a team, learn to live together, and learn to change ourselves and the environment. All these competences cannot be formed without advanced systemic thinking that defines the unity of consideration in any activity of the economic, social and environmental component, past, present and future, personal and global, morality and law ones.

Characteristic features of the noospheric-information (leading) model of education are determined by: globalization, continuity, personal orientation, increasing the diversity of educational standards and specialties, the use of distance education, networking [11].

The IMO supports global standards for sustainable development (safety and environmental protection) which are important for sea and river transport. The IMO has developed its own standards, which are based on economic, social and environmental sustainability, where shipping safety is a top priority.

At a symposium on World Maritime Day, September 26, 2013, the Secretary General of the International Maritime Organization, Koji Sekimizu, noted that since the global economy cannot exist without shipping, shipping will play a central role if the world wants to achieve sustainable development. At the global maritime trade market, shipping is one of the main links in multidimensional transport processes in the structure of the sea and river transport industry.

The emphasis in the maritime industry is the idea that the future depends on competent maritime professionals, and the establishment and research centers on maritime education should play an important role in this. They have the potential to introduce new innovative and digital teaching methods.

The Report about Maritime Sustainability highlights that education and training in developing countries are critical to a sustainable shipping system [12].

D. Krause, S. Diop, B. Brown and D. Troost say that sustainable maritime development depends on knowledge of the marine environment and access to it through training [13]. They conclude that maritime training and education is not just one of the aspects of sustainable maritime development, but also a tool to accelerate the proliferation of the paradigm in the marine industry.

2.2 Sustainable development of networking cooperation

The spheres of social activity of the information society are education, scientific and technological sphere, mass communications, information service and maintenance of various networks of information devices [3].

The issues of educational informatization are covered in the scientific works of A. V. Spivakovsky, S. O. Semerikov, V. V. Osadchyi, K. P. Osadcha, A. M. Striuk, Y. O. Modlo, M. S. Lvov, V. N. Kukharenko.

V. V. Osadchy and V. S. Kruglyk highlight the following global trends in the development of information technology in education: understanding ICT competences as a means of gaining all other competences for life-long learning; ensuring equal access to computer equipment and information on the Internet to all sections of the population; focusing on the free access of each member of society to the Internet information resources and the participation of everyone in the information society; creating the information society that respects human dignity, freedom and human rights; use of information and communication technologies for the benefit of people; development of distance or virtual type of training; introduction of a system for assessing the state of informatization of an educational institution; introduction of a global cybersecurity culture; implementation through ICT-continuous and adult education, professional retraining, lifelong learning.

This leads to the modernization of the training of maritime professionals using modern information technologies, among which distance technologies, augmented/virtual reality technologies stand out.

For students in the information society era, Internet space is an important medium of communication. The online environment performs important functions in the process of youth socialization – informative, regulatory, educational, cognitive, socially-communicative ones; creates an opportunity to find appropriate reference groups and meet the need for self-fulfillment of young people [14].

Networking, as a methodological principle, is the basis of a new form of education – the networking, which is legalized in Article 9, paragraph 5 of the Law of Ukraine "On Education", which states that the networking form of education is a way of organizing education of the educational recipients of education, thanks to which the acquisition of the educational program takes place with the participation of different educational entities that interact on a contractual basis [15,16].

The use of distance learning technologies (e-learning, m-learning) covers not only specific specialties or educational programs, but is an important strategic tool for the development and positioning of higher education institutions, enhances the innovative potential of the whole organization, and as a consequence increases the competitiveness of its graduates. The prevailing era of Web 2.0, an era of interactive web resources and communities that allows the user to become actively involved in the processes of their dissemination, discussion and development, as well as the creation of individual learning and social spaces, controlled even from a mobile phone, cannot leave the teaching system unchanged in a static web-based academy that only reads them from your computer and doesn't allow communication or interaction.

The implementation of distance learning technologies should include: communication and exchange of information at a distance; taking into account individual cognitive abilities of students (personalization); interactivity; mobility and virtual collaboration. All this can be realized in the process of professional training of the cadets of the Maritime Academy through the use of electronic and mobile training, virtual and augmented reality technologies on simulators. That is why today the direction of distance (electronic) education development is needed.

The scientists who studied innovative technologies in the training of future maritime professionals are following: I. Popovych, O. Blynova, M. Aleksieieva, P. Nosov, N. Zavatska, O. Smyrnova [14], A. Yurzhenko, H. Popova [17], V. Chernyavsky,

O. Volska, N. Panchenko, A. Vasiljevs, T. Bezverhnuik, S. Voloshynov [18].

The development of computer networking technologies is becoming one of the foundations for the distance learning, e-learning and mobile learning, which are effectively used for various forms of learning, including blended learning.

According to the modern level of development of distance learning technologies, there are creation and use of software complexes and e-learning tools of different orientation, including learning management systems (LMS), which integrate tools for administration, communication, assessment of knowledge, development and support of distance learning courses [19].

Therefore, a flexible education system is essential, enabling students to acquire knowledge where and when it is convenient for them; and it is necessary for the student to learn independently to work with information, acquire educational and subsequently professional competence [20,21].

Nowadays the competency-based approach is the methodological basis of distance learning [22, 23]. It allows each student to: actively engage in the process of mastering new subject content; learn operational and technical means of performing activities; create their own learning trajectory; independently plan and control the rhythm of training; independently plan and control the level of competence formation.

2.3 Organization of networking cooperation at Kherson State Maritime Academy

The ultimate goal of Kherson State Maritime Academy (KSMA) cadets' training is not the acquisition of knowledge, skills and competences, but the level of their competences achievement, i.e. the ability to use their knowledge, skills and abilities in a particular situation, and in maritime education even in emergency situations [24, 25].

KSMA took out a charter for training foreign nationals in basic accredited fields (specialties) of the maritime industry on June 30, 2010.

International students from Azerbaijan, Armenia, Bangladesh, Belarus, Ghana, Guinea, Georgia, Kazakhstan, Egypt, Cameroon, Cyprus, Ivory Coast, Lebanon, Libya, Moldova, Nigeria, Pakistan, Portugal, Russia, Tunisia, Turkmenistan, Turkey study at KSMA. As of December 1, 2019, 120 foreign nationals are studying at KSMA, 78 of them are full-time and 39 are part-time students; 8 English language classes are formed; 3 students are at the preparatory department.

Successful adaptation of international students to study in Ukraine is possible in case of creation of a comfortable infrastructure for life for them, rapid adaptation to local traditions.

For this purpose, a questionnaire of international students studying at KSMA was conducted.

Questionnaires consisting of 23 questions were used for the study, concerning the characteristics of students' adaptation to learning, their attitude to the values of a healthy lifestyle, forms of leisure activities and more (Fig. 1).

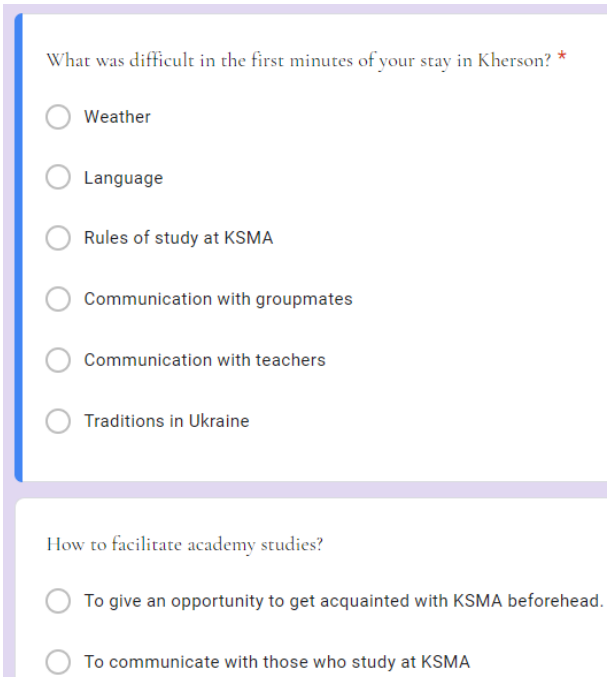

Fig. 1. Part of the questionnaire for foreign entrants.

The survey was conducted among 110 international students aged 17 to 22 years, studying at various courses and faculties of the Academy. It is of interest to study the issue of leisure and employment. The questionnaire raised the difficulty they encountered in Ukraine. They were ignorant of the Ukrainian language (16.8%), climate (24.4%), but there were also those who had no difficulties (20.2%). In order to support future entrants and to accelerate the adaptation of international students to the educational environment of the academy and living conditions in Ukraine, a course on the Moodle platform was created.

The main goal of the course is to pre-study English and to find out more about Ukraine, Kherson and Ukrainian traditions. The beginning of it consists of words of welcome, KSMA logo, main competences to achieve by the end of the course, news, information about author and teacher, online chat, questionnaire, check your competency questions, forum and different questionnaires (Fig. 2).

The course consists of the following topics to study:

- 1st Module: Unit 00 Personal data; Unit 01 People and places in Ukraine; Unit 02 Kherson;
- 2nd Module: Unit 03 Free time; Unit 04 Place to live; Unit 05 Holidays; Unit 06 Shops;
- 3rd Module: Unit 07 Family and Friends;
- 4th Module: Unit 08 Experience; Unit 10 Travel;
- 5th Module: Unit 11 Food.

To study separate topics of the course, gamified activities were created by a teacher (e.g. topic "Ukraine" in Fig. 3).

The gamified activities were created with the help of learningapps.org. The number of templates on this platform to create gamified activities is 24. The example of a gamified activity to study how much of Ukraine

foreign entrants know is shown in Fig. 4.

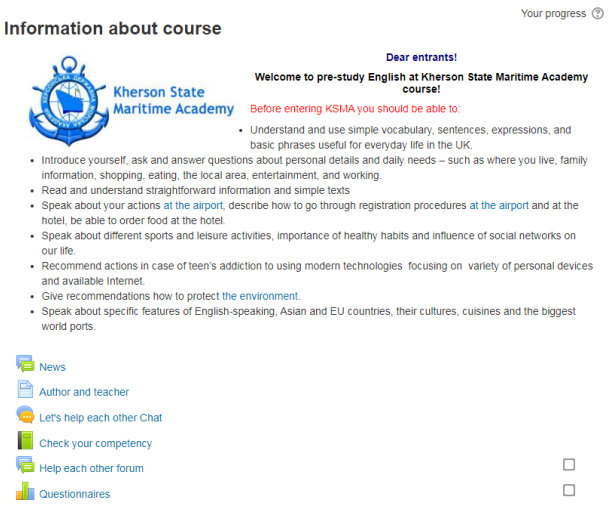

Fig. 2. The beginning of the e-course for foreign entrants in Moodle LMS of KSMA.

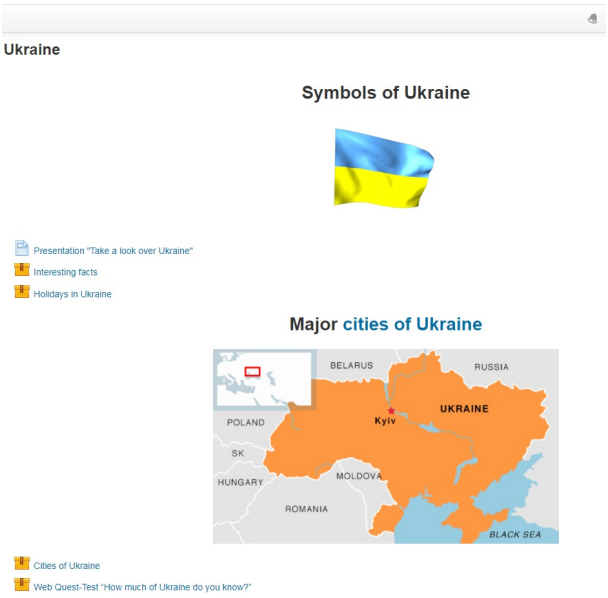

Fig. 3. Topic "Ukraine" in the Moodle e-course for foreign entrants.

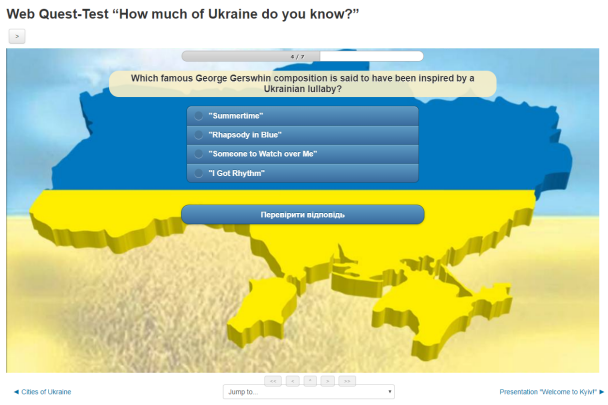

Fig. 4. Gamified activity "How much of Ukraine do you know?"

The course consisted also of forums to communicate with other students and cadets of KSMA. The forums allow encouraging discussion and improving communication, increase collaboration and provide better engagement. In forums of the e-course students can easily find assistance and support. The use of forums has many advantages (they improve communication, increase collaboration, and ensure better engagement).

One of the activities is video watching. During English classes at KSMA students of the second year made subtitles for various videos about Kherson and KSMA and with the help of teacher downloaded them to the course for foreign entrants. The task for entrants is to watch the videos and, using e-Glossary, to find the definitions of unknown words.

The example of the part of the e-course is shown in Fig. 5. This figure shows Unit 10 "Travel" of the 4th Module. It includes the following:

- gamified activities on matching words with definitions;
- listening and writing the answers;
- matching pictures with their names;
- multiple choice;
- studying colorful presentation (Prezi website);
- watching videos about Kherson;
- writing unknown words into Glossary; doing a test (Stop and check).

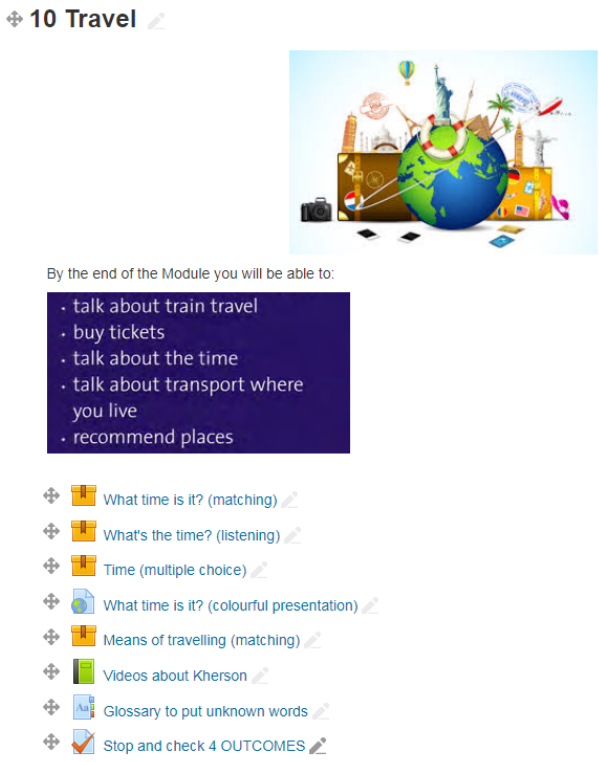

Fig. 5. Unit 10 Travel.

One of gamification elements is use of badges. It is realized with the help of Moodle LMS option – badges (symbolic rewards given to students for different achievements and displayed on a user's profile). Their main goal is to show the progress and motivate future students to succeed. The part of different badges is represented in Fig. 6.

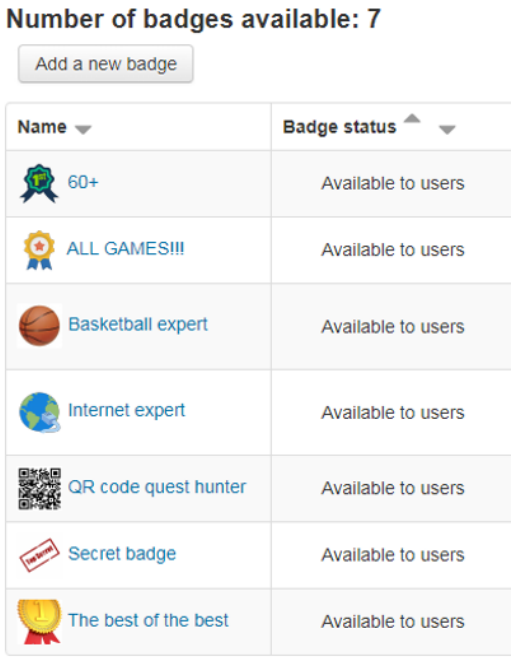

Fig. 6. Examples of badges given on the e-course for different achievements.

One of the advantages of using such a course use for foreign entrants is implementation of the principle of individual educational trajectory. The e-course is flexible in content creation and various assessment tools. Conduction of formative assessment allows teachers and tutors to identify the educational material that the cadet has not mastered. After testing, a new training program is formed from this material with the use of new training content, and so the training is organized until the results of the formative assessment are satisfactory.

Another advantage of the e-course is the opportunity to receive fast feedback, possibility of visual presentation of educational material and critical reflective learning and most importantly –motivation increase [26]. In this way Moodle LMS and the implementation of the idea of advanced professional education will not only significantly increase the possibility of a person's self-determination in the world of professional labour, but also help a person to adapt to the conditions of a dynamically changing maritime industry [27, 28]. And by increasing the general and professional literacy of future maritime transport specialists in constantly changing environment, it will contribute to the effective development of production and the economy as a whole.

3 Conclusions

Noospheric catastrophes require substantial analysis, and all the forces of the world community are aimed at combating them and their consequences.

The ways out of this situation, according to the concept of sustainable development, consist primarily of the technical and technological, information and computer modernization of the society's structure. Education is the key to sustainable development, because through education values, preferences, lifestyles are introduced that are necessary for the development of society. The basis for quality education today should be fundamental, cross-curricular, scientific and systematic, the formation of critical thinking, problematic learning, active participation of educationalists in the process of obtaining knowledge. And lifelong learning is an indicator of a person's effectively developed professional competence.

The education for sustainable development is now at the stage of forming meaningful educational conditions for the formation of such a generation. As the result of our study, the e-course in Moodle LMS for network interaction was created. This is the factor of sustainable development. Research in the field of sustainable development, as a rule, requires cooperation between scientists of different disciplines, between scientists and representatives of business and society, as well as cooperation between educational institutions and universities of different countries. Mutual learning based on real case studies requires an interdisciplinary approach to solve problems in an ever-changing world and to increase the level of network interaction and self-organization. Thus, one of the promising tools for improving the quality of education in the interests of a sustainable future is the development of effective tools and models of network interaction based on modern distance technologies. We see the prospects of further research we see in expanded cooperation and established networking with foreign institutions.

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Sustained English lingua-cultural education: a solution for Ukraine

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Abstract. Ukraine, as a state striving to join on the parity basis the international community of developed and democratic countries, lacks some important prerequisites for achieving this goal. Besides several economic and political factors making obstacles for the desired achievement, of no lesser importance are the humanitarian factors, such as the monolingualism and monoculturalism of a substantial part of Ukrainian population. They preclude unimpeded mutual understanding and mutual acceptance, as well as free unimpeded contacts, between many Ukrainian citizens and their European counterparts. In this aspect, the solution for Ukraine can be found in sustained foreign language lingua-cultural education of the broadest strata of Ukrainian population that could open for the people a way out in what concerns their ability to communicate freely and fluently all through the Western European space sharing with the people living there not only the language of international communication but also the cultural approaches and beliefs. The article discusses the ways of developing such sustained (life-long) English lingua-cultural education for the young generation of new Ukraine. It analyzes the section of that education to be implemented at Ukrainian non-linguistic tertiary schools with the aim of designing its efficient model.

1 Introduction

Ukraine is a young and aspiring state that from the very first days of its independence has set itself the goal of leaving in the past the fetters of the Soviet regime and entering on the parity basis the community of developed and democratic countries of the world and first of all, the community of developed and democratic European countries.

Quite a number of obstacles lie in the way of achieving this goal – first of all, the economic and political ones, but those are beyond the scope of this article. We are concerned with the obstacles rooted in the humanitarian field, namely those that concern the issues of linguistic and cultural policies. The presence of such obstacles is the result of the fact that Ukraine is distinguished by monolingualism and monoculturalism of the majority of its population while the distinctive features of the European Union countries are multilingualism and multiculturalism which are officially considered as "the supporting pillars" of the Union's language and cultural policy [1; 2; 3].

It would be wrong to say that Ukraine is a purely monolingual and monocultural society since Ukrainian-Russian bilingualism (or Russian-Ukrainian in the Eastern regions of the country) is all-pervasive and the features of Ukrainian and Russian cultures are sometimes so intermingled, due to historic causes, that their separation often becomes impossible or very hard even in theory. But this Ukrainian-Russian intermixture with its roots in the common past within the Russian Empire and the former Soviet Union is a very far cry from the multilingualism and multiculturalism of today's Europe. Both Ukrainian and Russian as Slavonic languages cannot serve as the intermediary languages in communication with the representatives of the Western European nations (whose languages mostly belong to the Germanic and Romanic families), and the culture and lifestyle of the Ukrainian people with their roots, as it has already been said, in the Soviet past are poor grounds for establishing mutual understanding with Western European counterparts.

This is why the solution of the humanitarian problem outlined above lies in foreign language lingua-cultural education of the broadest strata of Ukrainian population, the education with "the European vector," i.e. aimed at such language and culture training of Ukrainians that would bring their language development on a par with the language development of the citizens of the European Union and make their cultural development compatible with the cultural development of the citizens of the united Europe. Here it is worthwhile to remind that the European Union bases it language policy on the requirement for citizens of the united Europe to have a command of at least four languages: the language of the country where they permanently reside, the language of international communication (such as English), one more European language, and the regional (local) language as a safeguard against losing some less spread local languages and cultures, thereby impoverishing the cultural heritage of humanity as a whole [1; 2; 3]. Actually, what is meant here is sustained lingua-cultural education of European

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citizens that would help them, while preserving their own linguistic and cultural identities, achieve penetration into, full acceptance of, and total tolerance towards linguistic and cultural identities of representatives of other lingua-cultural communities.

A similar sustained lingua-cultural education may and should be introduced in Ukraine but this is worth doing only in case if a truly efficient and all-embracing system of that education is developed. The goal of this article is to try and substantiate some fundamentals for creating such a system suggesting the prolegomena for its elaboration and an efficient model of a considerable section of the system – sustained English lingua-cultural training of non-linguistic university students in Ukraine.

2 Sustained (life-long) lingua-cultural education of the young generation of new Ukraine: prolegomena for developing a sustained English lingua-cultural education system

In fact, sustained lingua-cultural education system already exists in Ukraine, and it was developed and introduced in the very first years of its independence. But it concerns only one language and one culture – the Ukrainian language and culture [4; 5; 6; 7]. There is no doubt in the necessity of introducing such a system, especially in the Eastern and central parts of the country where centuries of Russian domination have led to almost total eradication of that language and culture. The system of sustained Ukrainian lingua-cultural education, though it cannot be considered as fully successful yet, nevertheless has started reversing the trend of de-ukrainization that was very prominent both in the times of tsarist Russia and the Soviet Union. Nowadays, Ukrainian language and culture are gaining grounds even in the regions of the country that have traditionally been Russian-speaking. Such success of ukrainization can be ascribed not only to legislative and promotional measures (TV, cinema, the legislative regulation of the use of Ukrainian in the media, etc.) but to sustained Ukrainian lingua-cultural education as well. Even a Ukrainian born in the Russian-speaking family environment cannot help learning Ukrainian and the Ukrainian culture because from the moment he or she joins the nursery school that language and culture is permanently taught to him or her: at primary, secondary, and high schools, in his/her university and post-graduate studies, and even (when he or she graduates) at work where the use of Ukrainian and not of Russian is becoming more and more an everyday occurrence, more and more spread, even in predominantly Russian-speaking regions.

The experience gained in Ukraine in developing the sustained Ukrainian lingua-cultural education and the sustained education in general (including the sustained Web-education [8]), as well as the experience of other countries in introducing language education for sustainable development [9], may and should be used in the elaboration of sustained English lingua-cultural education in Ukraine making such education life-long, just as the Ukrainian lingua-cultural education has become. The reasons for making English, among all foreign languages, the primary candidate for sustained (life-long) lingua-cultural education in Ukraine are quite obvious.

Not only is English more than just an international language, having become a planetary or global language of communication in today's world. It even ceases to be regarded as a foreign language in very many countries, where it is not the mother tongue of the population, turning into something that everyone has no choice but to be in command of because the lack of such a command is somewhat akin to illiteracy [10]. The current attitude to English is also colored by the fact that nowadays the lifestyle and everyday cultures of many developed countries are often modeled in many features in accordance with the lifestyle and everyday culture of the English-speaking nations, especially the USA. Therefore, a person having a good command of English and aware of the peculiarities of lifestyle and everyday culture of the English-speaking nations can feel himself or herself, if not at home, then, at least, quite comfortable almost everywhere in the developed and civilized world. Hence, the inevitable conclusion that all the new generation of Ukrainians must achieve a reasonably high (at least, the level B2 of an independent user [11]) command of English.

It is for achieving such a command and for improving it further that sustained (and even life-long) English lingua-cultural education is an absolute requirement for Ukraine. When this goal is achieved and English is spoken, written, and understood more or less fluently by the greatest majority of the Ukrainian population, the time will come for expanding the sustained foreign language lingua-cultural education system in the country. It will mean the inclusion of the second and maybe even third foreign languages into it (some attempts at such inclusion have already been made; however, as yet they are mostly successful at linguistic tertiary schools where future specialists in foreign languages are being trained). But now the crucial issue is how to make sustained (life-long) English lingua-cultural education an organic and integral part of the Ukrainian education system as a whole and how to make that part truly efficient.

It should be stated that sustained (life-long) English lingua-cultural education system is already in existence in the country. Children very often start learning English at a very young age at nursery schools/kindergartens and continue such learning at their primary, secondary, and high schools. The process is not interrupted in university education and even in postgraduate studies where courses of English are mostly mandatory. Even after that, English learning does not stop. The system of commercial English teaching to adults is quite developed in Ukraine, and this system is widely used (with greater or lesser success) by great numbers of adult people, up to quite an elderly age [12]. Consequently, in this country a person has all the opportunities of learning English from the earliest age and practically until quite an advanced age, so it may be safely said that a system of life-long (sustained) English teaching indeed functions. Another question is how successful that system is. Regretfully, the answer to this question is not

infrequently negative because after years of studying English even the university graduates (to say nothing of school-leavers) often do not know the language well enough to use it effectively for international communication [12]. This lack of success in teaching and learning English does not spread to Ukrainian tertiary linguistic schools preparing specialists in English. There, the results are mostly quite adequate, so these educational institutions will not be analyzed further. But the other kinds of such institutions often suffer from the low level of English of their leavers and graduates.

There are many reasons for that, some of which are often beyond the control of teachers of English: the insufficiency of contact class hours with students (especially at non-linguistic higher schools); the lack of adequate modern equipment (such as computer laboratories specifically designed for language teaching) and of high quality modern (but often expensive) teaching and learning materials, and even the unwillingness of some students to invest a lot of efforts into English language learning though it cannot be said that really many of them do not understand the importance of such learning for themselves and are totally demotivated. But there are two others reasons for making students' language studies unsuccessful that the teachers can control, and controlling them can greatly increase the efficiency of language teaching and learning – so much so that it can even compensate for some of the above mentioned disadvantages.

The first of those reasons is the ineffective and obsolete teaching methods, some of them even dating to the Soviet times, that not a few teachers are still actively using (for instance, the grammar-translation approach). This does not promote optimization and intensification of language studies, not infrequently demotivating students, especially those who, even without such a factor, are reluctant to invest much time and efforts into learning English (see above). The other reason is the fact that very many teachers of English in Ukraine do not combine students' language studies with cultural studies in their courses. Culture is taught episodically, fragmentarily and mostly it is not the communication culture of the English-speaking nations which is absolutely crucial for successful communication in English. As a result, students command of English, even when they achieve it, is one-sided – linguistic but not socio-cultural which often precludes successful communication in English.

In the entire life-cycle of sustained English lingua-cultural education the two problems outlined above should primarily be solved on the level of sustained English lingua-cultural education at non-linguistic tertiary schools where English is taught for professional purposes. On the one hand, English education there is probably the most important and central one for all such life-long sustained education. If a graduate of a non-linguistic higher school graduates with a good command of English for professional use, he or she becomes a specialist able to practice his or her profession internationally and constantly improve the English professional communication skills in the course of that practice (further sustained practical education). If not, the student graduates only as a specialist of local value and his or her sustained English education mostly stops for good. Unfortunately, this is quite often the case, that is why improving and enhancing the quality of English studies at Ukrainian tertiary non-linguistic educational institutions is of decisive importance for the overall success of all the sustained English lingua-cultural education in Ukraine.

This was the reason why such improvement and enhancement of the quality of English courses at non-linguistic tertiary schools were chosen as the subject matter of our article, and developing the relevant model and approaches was set as its aim. There were four of those approaches substantiated in our studies:

1. The principled pragmatism, or well-grounded eclectic approach to language teaching;
2. The constructivist approach based on experiential-interactive language learning;
3. The English language immersion in senior years of students' university studies;
4. The integrated 'language-and-culture' teaching and learning focusing on communication culture.

The following parts of the article are devoted to discussing these approaches with the aim of grounding them theoretically, elaborating the guidelines for their practical use, and analyzing what results can be expected from the introduction of these approaches.

3 Principled pragmatism in English language teaching at non-linguistic tertiary schools in Ukraine

Principled pragmatism was theoretically developed by B. Kumaravadivelu [13; 14]. He interpreted the principled pragmatism as the belief that there is no best method in language teaching, every existing method can contribute something useful to second/foreign language classroom practice, while practical teacher's ideas, reasoning and cognition, and not scholarly constructs, are crucial in shaping the content of everyday language teaching and learning and the ways of implementing such teaching and learning. This approach is called by us *the well-grounded eclecticism* because it presupposes uniting into one single approach the features of different, sometimes even contradictory, methodological approaches (eclecticism), but only those features that a teacher in his or her practical teaching can "weld" into a single and harmonious unity with no opposition between elements, so that the unity of those elements enhances the efficiency of teaching practice (well-grounded eclecticism).

Kumaravadivelu [14] saw the way to achieving such harmonious unity of features from different methodological approaches in pragmatically following 10 principles (principled pragmatism):

1. Maximizing learning opportunities;
2. Minimizing perceptual mismatches;
3. Facilitating negotiated interaction;
4. Promoting learner autonomy;
5. Fostering language awareness;
6. Activating intuitive heuristics;
7. Contextualizing linguistic input;
8. Integrating language skills;
9. Ensuring social relevance;

10. Raising cultural consciousness.

What these principles signify and what should be done to observe them in the teaching practice will be discussed both below and in the following parts of this article devoted to the means of practically implementing principled pragmatism in language teaching. But, initially, in this part of it, it is worthwhile to consider how the concept of principled pragmatism per se benefits and enriches the sustained English lingua-cultural education at non-linguistic tertiary schools where English is taught for professional purposes.

First, it permits the teacher who is following the communicative approach to language teaching and learning (as every modern teacher does and should do) to have free recourse to the language-form focused learning activities (the non-communicative ones) that the strict communicative approach disapproves of and even considers as its opposites [15]. Such a free recourse is important because the total absence of form-focuing not only often worsens the overall learning outcomes [16; 17] but may also demotivate adult learners, such as tertiary students, who frequently want and need first to analyze and process the language phenomena before they start using them fluently in communication. The opportunity of turning to language explanations and language form-focused activities whenever the teacher deems it desirable helps prevent some cases of students' demotivation, enhances learning outcomes, thereby contributing to successful sustained language education process. Besides, it fully meets the above principle of pragmatism/well-grounded eclecticism requiring fostering language awareness, which means ensuring learners' better understanding of the language system. It is this better understanding which is the primary cause of the adult students' enhancement of learning outcomes already spoken about in this paragraph. Better understanding by students of the language system also helps prevent perceptual mismatches or, at least, minimize them (see the second principle of principled pragmatism above). The mismatches in question are the discrepancies between teacher's intentions and student's interpretations of those intentions, so that those discrepancies can cause the learning outcomes unexpected and undesirable for both the teacher and the learners. Language form-focused explanations prevent or minimize such mismatches, again enhancing learning outcomes and learners' motivation in sustained English language education.

Second, by its very essence the principled pragmatic approach requires that the teacher turns to all possible sources in search of teaching and learning resources and opportunities. For instance, those resources and opportunities can be found on the Internet, and the teacher can use them not only himself/herself for obtaining new additional teaching/learning materials and learning tasks for use in the classroom. He or she can also promote his/her students' out-of-class Internet search for finding learning information and for online learning of English in general. This requirement concerns in-class students' learning activities as well. They may and should be intensified and optimized by cooperative learning [18] when learning activities in class are mostly not teacher-fronted but done in pairs and small groups. These and many other learning resources and opportunities that the principled pragmatic approach makes mandatory for use not only help compensate for some of the objective factors impeding the language learning process that in the preceding part of the article were mentioned as being beyond the teacher's control (for instance, out-of-class Internet learning compensates for the scarcity of in-class contact hours and lack of cutting-edge learning facilities and coursebooks). They, especially the online and cooperative learning, also make students' learning activities mostly autonomous [19] and safely autonomous because the teacher is always there – not so much as an instructor but as a facilitator [20], permanently ready to facilitate autonomous students' learning whenever there is a difficulty or obstacle. Such a "safe" learner autonomy, due to its highly independent and creative nature, cannot fail but to enhance the learning motivation, thus helping to solve one more objective problem in language teaching. The above-discussed compulsory way of implementing the principled pragmatic approach ensures the implementation of three of its principles as well, those of: maximizing learning opportunities (e.g., by way of using online learning), facilitating negotiated interaction in the target language (which is an inextricable feature of all kinds of cooperative learning), and, most importantly, promoting learner autonomy (see the explanations above).

Third, in what concerns the sustained English lingua-cultural education at tertiary non-linguistic schools, the future profession-oriented nature of such education makes it mandatory for the principled pragmatic approach to find practical support in all the latest developments in the area of English for Specific Purposes (ESP), i.e. teaching English for achieving purely professional goals [21]. One of the most prominent of such developments is *content-based instruction* [22; 23]. It provides for "… the integration of content from the subjects of students' majors with the goals of target language teaching. It ensures parallel acquisition of knowledge from certain non-linguistic disciplines together with acquisition of the target language and the skills of communicating in it. In such instruction, the ESP curriculum is most closely linked or even based on the curricula of one or several of students' majoring disciplines so that learning the target language content follows the requirements of learning some professional content from the majoring disciplines through the medium of the target language. The development of students' target language communication skills proceeds mostly subconsciously through their learning in the target language the content matter from the majoring subjects. In this way, content-based instruction eliminates the gap between language learning and learning professional subjects ensuring students' learning the latter through the medium of the former." [24, p. 73]. Since principled pragmatism presupposes using everything that can help in achieving the learning goals – if there is no opposition to or contradiction with the other parts and elements of the teaching/learning system, which may ruin its structure, – basing the principled pragmatic system of teaching English at tertiary non-linguistic schools on content-based instruction is inevitable. And this, in its turn, meets such principles of that pragmatism as contextualizing linguistic input (learning the language

in the context of future profession) and ensuring social relevance (teaching and learning the language in direct connection with the social needs of training English-proficient specialists in different fields).

Thus, after analyzing the fundamentals of the principled pragmatic/well-grounded eclectic approach, even without considering the practical ways of its implementation, it is revealed that when the approach is introduced into sustained English lingua-cultural education at tertiary non-linguistic schools, at least seven out of ten of its principles cannot fail but to be brought to life. These same principles and some others are brought to life as well if the principled pragmatic approach is implemented in teaching practice through constructivism based on experiential-interactive learning of English.

4 The constructivist approach based on experiential-interactive language learning

Constructivism in pedagogy [25; 26] presupposes "… providing students with opportunities of "constructing" their own knowledge and skills through practical experience in real-life or modeled activities. In this case, students acquire their knowledge and skills as a by-product of their real-life or modeled activities, thus internalizing (appropriating) the knowledge and skills and not just learning them" [24, p. 13]. From the quoted definition it can be seen how ideally compatible the constructivist approach is with principled pragmatism in language teaching and how ideally adapted it is to the sustained language education conditions. By imposing on students themselves the task to construct their own knowledge and skills, the constructivist approach puts into action eight out of the ten principles of principled pragmatism (see above) because: 1) the learning opportunities are automatically maximized since learners themselves maximize them to self-construct their knowledge and skills; 2) students minimize perceptual mismatches as they learn independently with the teacher as a facilitator, not an organizer or "explainer;" 3) they inevitably learn cooperatively, helping each other to achieve the common goal, i.e. through negotiated interaction among themselves (and with the teacher), being at the same time 4) highly autonomous in the process of this interaction; 5) learners' language awareness increases in the process of self-constructing their language knowledge and they are in constant need of 6) using intuitive heuristics in the process of knowledge and skill self-construction. Besides, since self-construction of language knowledge and communication skills is done through the content matter of future profession (see the preceding part of the article), 7) contextualizing the linguistic input and 8) providing its social relevance is ensured. It is clear that if such a mode of learning English is acquired and appropriated by students, it can and often will turn into their habitual behavior in such learning, i.e. the language self-education may become not only sustained, even after the language course at their higher non-linguistic school is finished, but also life-long.

Constructivism (as a theoretical foundation of a sustained foreign language course at tertiary non-linguistic schools) in ESP teaching and learning practice is implemented only through the experiential and interactive (experiential-interactive) language learning system [24; 27]. When teaching ESP, or English for professional purposes, experiential learning is such an organization of the teaching/learning process which gives opportunities of constantly modeling the future specialists' professional activities in their language learning activities, so that the latter model the professional communication. What is specific for language learning is the fact that such quasi-professional communication is implemented not by the means of learners' mother tongue but by the means of their target language, thus allowing for the acquisition of the foreign language and communication skills mostly involuntarily and subconsciously as a by-product of modeled quasi-professional activities and quasi-professional target language communication.

The research [24] has shown that experiential learning when teaching English for professional purposes at Ukrainian non-linguistic tertiary educational institutions means designing the teaching/learning process as an uninterrupted succession of specific professionally-oriented creative learning activities:
– role plays and simulations,
– students' brainstorming, case studies, discussions,
– presentations,
– workshops,
– learning projects,
– writing professional essays, abstracts, summaries, etc. in the target language.

All those activities can be successfully performed if they are constantly accompanied by out-of-class learners' autonomous search for information in the target language (mostly on professional Internet sites in English) and by processing the information found through reading and listening with the aim of providing sufficient professional data required for doing all the profession-oriented creative learning tasks above.

Even the listing of typical experiential learning activities given above makes clear two very important features of all of them. The first is that they are all interactive. Role plays/simulations, brainstorming, case studies, discussions, project work simply cannot be done individually – interaction in the target language with other students while working in pairs, small groups or even using the whole-class interaction pattern is the basic condition for organizing them. Presentations can be prepared individually (though quite expedient are presentations on some topic prepared by two or even three students), but they are always delivered in the interaction with the entire classroom of other learners. This is even more so when in experiential teaching and learning students' presentations are transformed into workshops where the presenters not so much present the information themselves as introduce the other students to the topic being discussed, give them tasks aimed at processing and achieving full understanding of that topic, monitor the students' performance, and finish the workshop by discussing the results and drawing conclusions. Even the

experiential writing activities (see above) are interactive because they are done using the process approach [28] when every piece of students' writing is first outlined in small group discussions (team writing) and every individual writing draft is peer-reviewed and peer-commented.

The information search and information processing (through reading and listening) activities done in experiential learning are also interactive though the search, reading, and listening themselves may be done totally individually (however, pair and small group work is quite possible in this case too). The interaction meant here is students' interaction with out-of-class sources of information – primarily, professional sources, like professional Internet sites in English used in ESP courses at non-linguistic tertiary schools for collecting information needed for completing creative experiential learning tasks, such as project work and the others.

Because of all this, it would be more accurate to speak about not experiential but *experiential-interactive* learning, as it has been done from the beginning of this article. Such deeply interactive and, consequently, cooperative (see the preceding part of the article) nature of experiential learning activities puts into action the best advantage of cooperative learning – peer-teaching because working in close cooperative interaction, students involuntarily share their personal stocks of knowledge, experience, and skills, thus teaching each other and learning from each other, which greatly enhances and improves the learning outcomes [18].

The second important common feature of all the experiential learning activities is integrating in them the development of the four basic language/communication skills: speaking, listening, reading, and writing. The experiential learning tasks are all creative, and, as it is clear from what was said above, doing them requires collecting information needed for their completing which means reading and listening in English. The tasks themselves are done through speaking or writing (and, quite frequently, first speaking and then writing, like in project work), while listening to other students reporting on their results in task completion is also included. So, the four communication skills become thoroughly intertwined since the communicative activities of speaking, listening, reading, and writing always follow each other in the consecutive and orderly manner, each receiving its fair share of attention. Not only does it help developing all the communicative skills in close unity/integration, which always ensures better results of such development [29], but it also meets the requirement of one of the important principles of Kumaravadivelu's principled pragmatism: integrated language skills [14].

At the beginning of this part of the article, it has already been said that the constructivist approach practically implemented in experiential-interactive learning activities perfectly fits and even follows the principled pragmatic approach and is highly compatible with the sustained English language education at a non-linguistic higher educational institution. This latter compatibility is further reinforced by the fact that at such institutions a constructivist (experiential-interactive) course of English for professional purposes paves the road to English immersion in courses of professional disciplines in senior years of students' university studies. This issue is discussed below.

5 The English language immersion in senior years of students' university studies

The methodology of target language immersion [30; 31] is based on teaching non-linguistic disciplines (mathematics, physics, history, tertiary school professional subjects, etc.) at secondary, high, or higher schools through the media of the second/foreign language to be acquired by students. Our research, including the experimental studies, has shown that at non-linguistic tertiary schools, if the course of English for professional purposes (which is usually taught in the first, second, and sometimes third years of university studies) is content-based and designed as a constructivist/experiential-interactive one, students get fully prepared and ready to continue their English acquisition in English immersion courses that they start in the third, or the fourth at the latest, years of their university tuition [24].

In this case, the English immersion courses are regular courses on professional disciplines taught by English-speaking professors and teachers specializing in those disciplines, and these professors and teachers teach their subjects in English instead of learners' mother tongue. The conscious focus of attention is only on professional subject matter of the disciplines, while learners' command of English is being improved and advanced mostly involuntarily without any teacher and learners' concentration on language specifics in the process of tuition.

Our experimental research has demonstrated that, if the basic non-linguistic university course of ESP is taught as a totally content-based and constructivist (experiential-interactive) one, by the end of the second year of that regular English course students mostly achieve the B2 (independent user) level [11] in their command of the target language to be acquired for professional communication [32]. This ensures, as was also proved experimentally [33], a smooth transition, beginning from the third year of university studies, to introducing English immersion programs into courses of professional non-linguistic disciplines. Such introduction is successful if it is graded and gradual – starting with the least difficult kind of immersion programs (preliminary immersion) in the third year, passing to more complicated and sophisticated but still somewhat simplified ones in the third and fourth years (partial immersion), and ending with entirely non-adapted total immersion programs in the final years of learners' university studies [33; 34].

If such an approach is implemented, students frequently attain the C1 level [11] (a much higher one than is required by the curriculum and syllabi) in their mastery of English for professional purposes [33]. One of the most important reasons for such a success is the fact that following the suggested approach ensures a truly sustained English language education all through the years of learners' studies at their university: they begin

acquiring English in their ESP course from the first year, learn it in that course in the second and, sometimes, third years, and from the third year smoothly proceed to English immersion in courses of special professional disciplines. Such immersion may continue until the end of university studies solving, though on the level of non-linguistic higher schools only, the problem posed in Section 2 of this article – that of providing university graduates with sustained acquisition of English for professional communication. The suggested approach, by developing the means of solving the indicated problem on the level of one type of educational institutions, outlines the ways and means of solving it in a similar manner in all the other types of such institutions.

However, the approach developed by us has been discussed above in only one, though the most important, aspect of its implementation – that of ensuring sustained English language education. But in Section 2 of this article it was repeatedly emphasized that the sustained English *lingua-cultural* education is required. How the cultural constituent is superimposed on the elaborated approach is analyzed below.

6 The integrated 'language-and-culture' teaching and learning focusing on communication culture

Teaching culture, or socio-cultural competence, is an absolute prerequisite for learners to achieve the adequate development of their target language communicative competence, as it has already been said in this article and is repeatedly stressed in all the works regarding the development of such competence and learners' cultural adequacy in English communication [35; 36; 37; 38].

At higher non-linguistic educational institutions there is no opportunity of teaching target language community's culture in a special course, like "Language and Country Studies" taught at higher linguistic schools. Not only such a course is not included in the curriculum but also there is simply no time for it. Therefore, the only option is to superimpose the culture studies on the language studies both in the regular course of ESP and even in the English immersion courses on professional disciplines. For instance, if in the regular English course such experiential learning activities as students' discussions are organized, before they start, the teacher may tell the learners that in English formal discourse it is impolite to express direct and categorical disagreement with your interlocutor by saying: "You are wrong!" Only something milder is acceptable, like: "I agree with you up to a point, but on the other hand, …" Then, there may even be a short training task, after which the discussion proper will start. In a similar manner, in an English immersion course for students of Business and Economics when the ways and means of conducting business negotiations are discussed, the teacher should inform the students that in international business negotiations when an American businessman takes off his jacket and rolls up the sleeves of his shirt, it means that for him the preliminaries are over and he is ready to start talking business. But for a German businessman the implication is directly opposite: a desire to stop negotiating and relax for a while.

Such a manner of superimposing cultural information on ESP or English immersion courses does not require much time and efforts but keeps the cultural education sustained throughout those courses, simultaneously providing for the implementation of the last of Kumaravadivelu's principles [14] in the principled pragmatic approach – the principle of raising the learners' cultural consciousness. The latter ensures the complete implementation of this approach in all its aspects, which, in its turn, creates the required background for the efficient introduction of the constructivist/experiential-interactive approach.

Following such a mode of teaching the cultural constituent in sustained English lingua-cultural education allows learners to acquire all the cultural information that they really need for adequate professional communication in English but only on the condition that this information is properly and sparingly selected. Cultural information to be taught may be divided into two principal groups: the culture of the nation with a "big C" (literature, art, legislation, political structure of the country, etc.) and culture with a "small c," or communication culture, which can be either verbal or non-verbal [38]. It includes the cultural phenomena that make the communication culturally and socially acceptable in a given speech community [39; 40], which may be called the target language lingua-cultural community. The two examples of just such cultural information (both verbal and non-verbal) were given above, and it is only this last type of culture, restricted to strictly professional students' needs (their strictly professional communication in English), that should be taught at non-linguistic higher schools. Regretfully, the teachers of English not infrequently do something directly opposite – speak at length about English-speaking nations' "big C" cultures, so there is no time or opportunity left for teaching the really indispensable communication culture. Therefore, the contents of the cultural constituent of the sustained English lingua-cultural education at non-linguistic tertiary educational institutions should be selected as carefully (if not more carefully) than the language contents.

Everything said in this article leads to drawing some conclusions.

7 Conclusion

Ukraine, the country with the aspirations of becoming an integral part of Europe, urgently needs a system of ensuring the command of English as the language of global communication to the majority of its population, especially to the younger generations. Knowing the English language only is not enough, the culture of the English-speaking nations that has spread throughout all the developed countries in the world is of no lesser importance. It means the necessity of sustained (even life-long) English lingua-cultural education. Ukraine already has an experience of organizing such an education after developing and putting into practice the system of sustained Ukrainian lingua-cultural education. This

successful experience may and should be used for elaborating a similar system in what concerns teaching the English language and culture – as a preliminary to expanding that system to other foreign languages with the purpose of spreading multilingualism and multiculturalism among the broadest strata of the Ukrainian society,

The above article is devoted to discussing the development of the sustained English lingua-cultural education model for Ukrainian tertiary non-linguistic educational institutions with the aim of providing their students with the highest possible (up to C1) level of mastery of the English language and culture required for graduates' international professional communication. The elaborated sustained education model is based on four most important foundations when teaching English as a foreign language: the principled pragmatism, or well-grounded eclecticism, in language teaching; the constructivist language learning implemented through experiential-interactive learning activities; the foreign language immersion, and the integrated 'language-and-culture' teaching and learning focusing on communication culture. An important constituent of the model is its professional orientation towards the future graduates' professional needs in the language and culture of international communication. That orientation is brought to life, first, by way of introducing content-based instruction into the language course proper and, second, by way of designing English immersion programs for the courses of professional disciplines in the senior years.

All these components of the sustained English lingua-cultural education model are integrated, making a harmonious hierarchy shown in Fig. 1 below:

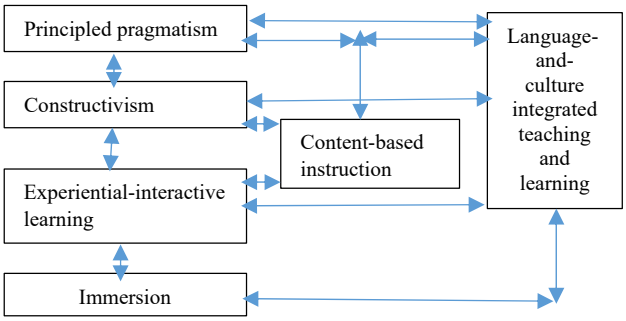

Fig. 1. Sustained English lingua-cultural education model for Ukrainian tertiary non-linguistic educational institutions

The introduction of the suggested sustained English lingua-cultural education system into Ukrainian tertiary non-linguistic educational institutions gives students an opportunity of achieving high levels of command of English for professional communication (as our experimental studies show, level B2 may be attained after the course of English [32] and level C1 after learning it in the English immersion programs [33]). Besides, such an introduction makes English language and culture education truly sustained – lasting all through the years of students' tuition at a non-linguistic higher school.

The prospects of further research in the same direction lie in attempting to expand the developed sustained English lingua-cultural education system to other types of educational institutions in Ukraine.

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Integration of information and communication technologies into the process of learning the course of English for specific purposes as one of the requirements for sustainable future development

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Abstract. One of the most effective ways to improve the process of teaching foreign languages for specific purposes is to use computer and Internet technologies in the education system. The computer-information model of education is a kind of transitional stage from the system of traditional methods of teaching foreign languages to the modern system of information education. The article describes the advantages and disadvantages of the most progressive and wide used technological means like computers, laptops, interactive whiteboards, tablet PCs and graphics tablets, whose implementation into the educational process can significantly increase the effectiveness of teaching foreign languages for specific purposes and help in organizing lessons. Moreover, various language learning multimedia tools such as Modular Object-Oriented Dynamic Learning Environment and digital presentations, and peculiarities of their use are highlighted. The research of experimental data has been carried out after several surveys among Tavria State Agrotechnological University students. The necessity of information technology implementation into the process of learning foreign language for specific purposes was analysed.

Introduction

According to the Sustainable Development Goals (SDGs) which have been adopted at the 70th session of the UN General Assembly, the providing high quality education is one of the most required conditions for sustainable future [1]. The rapid pace of changes in the world must integrate new perspectives in order to protect the environment, contribute to sustainable cities and community development, promote sustainable economic growth and create inclusive societies. The realization of these tasks requires a new approach to education.

The sustainable future development includes the cooperation and joint participation of professionals and experts from different backgrounds. Academic and labour migration has led to a growing need for learning foreign languages, not only for everyday communication but for successful communication with their colleagues from other countries. All these changes resulted in high demand for learning English as a language for specific purposes (ESP). Meanwhile, the 2030 Agenda for Sustainable Development emphasizes that learning opportunities should be increased and diversified, using a wide range of education and training modalities, so that all youth and adults can acquire relevant knowledge, skills and competencies for decent work and life [2]. Hence, critical thinking and problem solving, communication skills and teamwork, creativity and work-specific skills should be developed in the process of future specialists training. The course of English for specific purposes is aimed at acquisition of all mentioned above skills and forming the professional and communicative competence. In addition, the traditional teaching methods are expanded with the intensive introduction and application of new information technologies, as well as the use of all means of communication.

The purpose of this research is to analyse the influence of information and communication technologies (ICT) on the process of learning English for specific purposes which contributes to the formation of an intellectually developed creative person who is well oriented in the information space, ready for self-development and application of professional knowledge for sustainable future.

The development of revolutionary new products in the market of computer and office equipment is inevitably changing the relationship between the student and the teacher, and in general the entire education system. Today a vast majority of students often own computers (laptops, netbooks), tablets and readers with a high-speed Internet connection, which enable them to access any information in minutes.

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This has greatly influenced the teaching environment. Therefore, the teachers have to be not only the perfectly qualified specialists in their professional field but also to be competent in modern information and communication technologies. They should also be creative in producing and innovating new techniques and methods of teaching that could maximize the use of technology that fulfil students need in current time [3], understanding that the use of modern information technology is not a purpose itself, rather it is one of the most important components of the organization of the educational process in high school.

According to S. Symonenko et al., the practice of immersion into virtual environment in foreign language learning will enable students to feel themselves an integral part of the professionally oriented situation which is designed specifically to prepare the course participants for communication within. [4] Therefore, the common goal of all ESP teachers is to develop students' foreign-language communicative competence that would enable them to communicate at a professional level with specialists from other countries [5]. This implies a direct correlation between theoretical knowledge and practical skills in their specialty and foreign language learning. V. Klochko notes that students of higher education institutions – future specialists – need to acquire both professional competence and communicative foreign language competence. It is about acquiring the necessary knowledge, professional skills and abilities to use a foreign language in intercultural cooperation [6].

The specific nature of teaching a foreign language allows comprehensive use of information technology throughout the educational process, which significantly changes the model of learning, making the transition from teaching-centric to student-oriented system. The use of information and communication technologies contributes to the individualization of the main forms of learning and optimization of the acquisition of language structures at all levels, overcoming the monotony of the lesson in the process of forming foreign language communicative competence.

Authors of modern methods of teaching a foreign language consider information and communication technologies as means, methods and techniques of performing educational tasks and project work [7]; independent extracurricular work; creation of a virtual educational environment. Thus, the use of ICT makes it possible to control knowledge at all stages of learning the material, providing the necessary feedback between the teacher and the participants of the educational process, which helps to increase their level of knowledge and skills.

Taking into account the practical experience in teaching English for specific purposes, considerable attention should be paid to the use of multimedia technologies, which simultaneously use texts, graphics, video materials, sound effects, animation. All of this, together with interactive software, affects the emotional and conceptual areas, contribute to a more efficient assimilation of language material [7].

Teachers can use ready-made ICT tools (multimedia, educational software, digital presentations, etc.) during language training or create their own [8]. The advantage of the latter should be noted, because in this case the teacher has the opportunity to adapt the content of an ICT tool to the level of knowledge and skills of a particular group of students, to fill it with material that would be of interest to this group and would correspond to the curriculum and technical capabilities of a particular institution [9]. Therefore, the use of new information technologies greatly facilitates the activities of teachers and students in the process of learning the course of English for specific purposes.

1 The use of computers and laptops for learning English for specific purposes

S. Symonenko and V. Osadchyi put forward the idea that foreign language training of future specialists in any branch should keep pace with the realities of time and take into consideration existing transformations of communication in order to learn languages for the further successful functioning of specialists in their professional activities [10].

With the development of modern technology, computers and laptops have become learning tools that can visualize a variety of information. They affect all components of the training system: goals, content, methods and organizational forms of training, teaching aids, which makes it possible to solve complex pedagogical tasks, namely: the development of intellectual, creative potential, analytical thinking and self-realization. In addition, B. Drayton, J. Falk, K. Hobbs, J. Hammerman, and R. Stroud emphasized that the use of computer based classroom shows a real learning experience that increases learners' responsibility [11].

For the teacher, the amount of visual and video material in preparation for the lesson with this technical tool is unlimited, as there are many educational resources on any topic, and in various online libraries the specific visual materials can be found and reused.

According to AbdulMahmoud Ibrahim, ICTs help the student be exposed to language clockwise and definitely they help them to write and edit their work in order to produce a well published work. Likewise, computers encourage students to do extra work outside the classroom, play language games and, hopefully, gain extra exposure to the language and improve their progress in the language and support the student-centered concept [12]. Therefore, computer-based training provides the opportunity to organize the independent work of each student.

Integrating computer means into a regular lesson allows the teacher to shift part of his work to a computer, while making the learning process more interesting and intensive. Moreover, the computer does not replace the teacher, but only complements him. The selection of training software depends primarily on the current training material, students' language skills and their abilities.

The noted capabilities of the computer make it an excellent technical tool for various kinds of explanations

and generalizations of the phenomena of language, speech and speech activity.

Among the typical disadvantages of computer-assisted instruction is abuse of computer effects and redundancy of colours. Moreover, it's very difficult to adapt ready-made educational computer software on a subject to a traditional lesson, since it does not always correspond to the curriculum, methodological goals, and didactic principles in teaching.

One of the most common ways of controlling the gained knowledge and language skills is accomplished with the help of open information systems, like the Moodle LMS. Moodle is a package for creating web-based courses and is quite favourable for learning ESP with a great opportunity for personalization that enables the teacher to create on-line courses with exceptionally rich interaction [13]. In other words, it is a learning management system, courses, a virtual learning environment that allows creating a holistic working space for all participants in the educational process.

The large-scale implementation of this system in the educational process of Dmytro Motornyi Tavria State Agrotechnological University (TSATU) began in 2014-2015. The Moodle system is focused on cooperation and interaction between the teacher and the student during the classroom and extracurricular activities for the joint implementation of educational tasks (Fig. 1). The teacher has the ability to transmit a huge amount of information and control the gained knowledge and organize the learning process more rationally, making easy and understandable tasks and topics for independent study remotely through this electronic system.

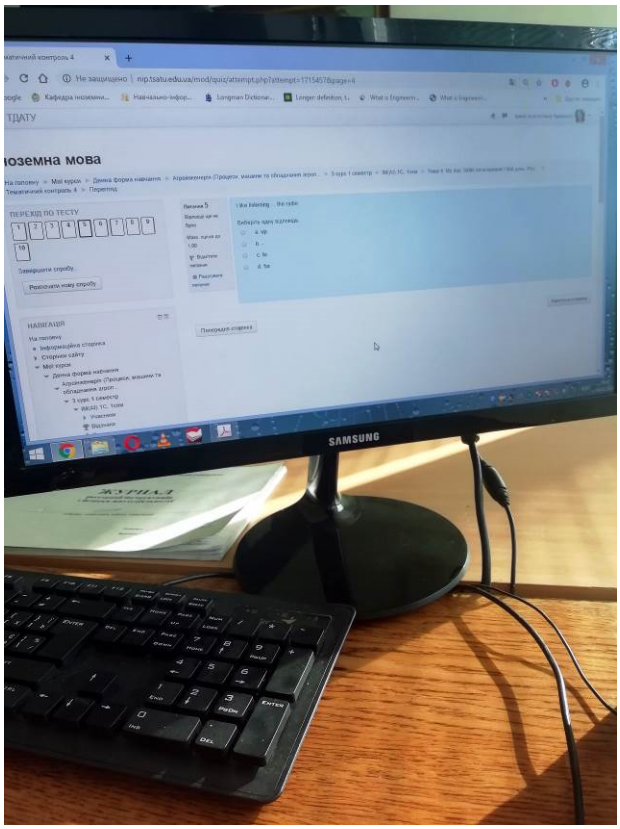

Fig. 1. ESP e-course based on Moodle LMS.

Teachers of the TSATU annually develop and actively use electronic educational and methodological complexes that include ESP curriculum, syllabus, self-study support packs and practical recommendations for studying foreign languages in a number of disciplines [14].

The named complexes are based on the use of modern e-learning technologies, which ensure the implementation of individual teaching areas with the direct supervision of a teacher and significantly increase the process efficiency of teaching a foreign language.

The advantage of using open information system is the mobility of training, since the electronic complex is available at any time in the classroom and outside the educational institution, so students can plan their curriculum, duration of the lesson and assignments at a time convenient for them, but taking into account the time limits established by developers.

Entering the Moodle LMS students choose a certain subject (Fig. 2). After reading and studying the material, strategies, recommendations, they consolidate their developed language skills by doing a test on each topic. At the end of the course, students must pass the final test in a fixed time and have a limited number of attempts. Their grades or score will be recorded in the group register. Furthermore, Marina D. Milovanović outlines the main advantage of Moodle system as the possibility to check the results right away [15].

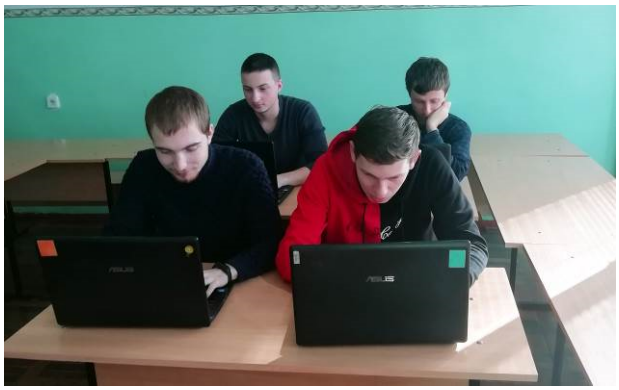

Fig. 2. Computer-assisted language learning in classroom.

Among the negative aspects of the Moodle system, in our opinion, is the fact that it is impossible to control the students' individual work in a distance. The teacher often has difficulties in defining the exact individual who completed the tasks and mastered the material to obtain a satisfactory grade, and be sure that no one else used the student's profile and helped him to get a higher grade.

In testing, it is impossible to exclude an element of randomness. For example, a student who does not answer a simple question may give the correct answer to a more complex one. The reason for this may be either a random mistake in the first question, or guessing the correct answer in the second. This situation can greatly affect the distortion of the test results and, accordingly, lead to the necessity of using the probability component in the analysis of the results.

As for the technical problems, one cannot but mention that the compilers of the mid tests and final tests

establish a certain number of attempts to pass them and do not take into account the congestion of the system or problems with the Internet connection at home or in the audience of the educational institution. The system may shut down, the attempt will be lost and the score will not be recorded in the register.

The development of quality test control is a long and difficult process. To work correctly with the Moodle LMS, the teacher needs to undergo special training. To master the skills of filling the subjects of classes, a bank of test questions, enrolling groups of students and teachers in a particular course of a discipline. Similar training is necessary for students with explanations and a sample test, for example.

Tests of educational achievements used in the system to assess the quality of training, mainly help to measure the students' gained knowledge on particular language skills. On the other hand, the system restricts the possibility to evaluate such language activities as speaking and writing.

2 Using interactive whiteboards for foreign language teaching

An interactive whiteboard is one of the most modern teaching tools, the technology of work with which is being actively mastered today by teachers of various subjects. It is one of the most powerful visual presentation tools that give the opportunity to place a large number of diverse information, the density of which is much higher than on a regular board.

Fully functioning interactive boards are typically connected to a computer, a multimedia projector, a projector mounting kit, AV face plates and speakers. The image from the computer monitor is transmitted through the projector to an interactive whiteboard, and touches on its surface are sent back to the computer via a cable or through wireless communication interfaces and are processed by special software [16].

According to the main characteristics we distinguish interactive boards for direct or reverse projection. For direct projection, the projector is located directly in front of the surface of the interactive whiteboard, and in the opposite – behind it. Individual interactive whiteboard models can be equipped with special handheld personal computers for data exchange. There are also expensive models of interactive whiteboards that do not use the projector, but have got a large touch screen plasma panel.

There are three types of interactive whiteboards:

1. Boards that fix the surface resistance when they are touched.

Such boards have a soft and flexible surface consisting of two parts. The resistance fixing material is separated by a small gap from the rest surface of the board and transmits signals to the computer when a special membrane is triggered. Such boards can be controlled not only by special markers, but also by the usual touch of a board or pointer.

Special markers can also be configured (using the supplied software) to display different colours. Such boards are very suitable for educational institutions, as they are reliable and do not require any special gadgets that can be lost or broken [16].

2. Boards that fix electromagnetic pulses.

These boards, like traditional ones, have a solid surface. It is controlled by special battery-operated electromagnetic markers. The surface of the board is covered with a grid of thin wires that capture a small magnetic field emitted by the marker.

3. Laser boards.

Laser boards have a solid work surface with infrared laser scanners mounted on the surface. These scanners detect the movement of a special pen, colour coded and transmit them to a computer. Also close to this technology are the DViT (Digital Vision Touch) boards, which use small digital camcorders, located at the corners of the screen and capturing each touch [16].

The greatest effect can be obtained by a teacher using all the features of the board. The interactive whiteboard with the help of a special marker allows teachers to move drawings, photos and texts on its surface, copy them, rotate, resize and shape. With this marker, they can not only draw on the surface of the board, but also control computer software, push buttons, select and drag objects. The marker in this case replaces the computer mouse. This feature allows many computer software to be used with the interactive whiteboard, including most of the existing multimedia computer educational software.

Also, teachers working with an interactive whiteboard can increase the level of perception of the material by combining various forms of information transfer – visual, sound and tactile. During the lecture, they can use bright, multicolour schemes and graphics, animation accompanied by sound, interactive elements that respond to the actions of the teacher or student. If necessary, it is possible to enlarge one or another element drawn on the board surface with one hand movement. Thus, competent work with the interactive whiteboard helps to optimize the learning process.

Remotely, managing the presentation, the teacher has more opportunities to provide individual assistance to the students, because all the constructions, schemes that he had to complete on the board during the lecture, are already on the slides of the presentation. Therefore, presentations are the most accessible and effective educational means which can be used at various stages of the lesson and various types of lessons, depending on the goal set by the teacher. They provide an opportunity for the integrated development of the speech skills of a student in the process of learning foreign languages.

Holding presentations diversifies the educational process and allows involving students in cognitive activities. And the preparation of presentations by the students themselves is clearly practical, since in the future they will have to work in enterprises and organizations where presentations are an urgent need for successful work and the fulfilment of their functional duties.

For example, during English for specific purposes lessons the second-year students of specialty “Agronomy” are offered to present their own reports on

the topic “Main peculiarities of modern education, its prospects and perspectives” using whiteboard technology. Thus, students have the opportunity to share their own thoughts on the set issue with others and manage the whole process of their presentation (Fig. 3).

Fig. 3. Interactive whiteboard in foreign language class.

Interactive whiteboards enable them to show their slides, videos, schemes which can help students thoroughly explain their points of view. Moreover, whiteboards lower the psychological barrier, allowing students to overcome their fear of public speaking, technology and begin using modern technology in educational and professional spheres [17].

Like any other interactive tool working on whiteboards requires previous training and deep knowledge of appropriate software. Besides, the process of calibration should be done before the first using and after some periods of time. The amount of available functions depends on the model of whiteboard and thus the price can be too high.

3 The role of tablet PC in learning English for specific purposes

Recently, increasing attention has been given to the use of tablet PCs in the educational process, that combine handwriting, mobility and computing power to support student-centered learning.

It is worth noting that the universities and higher educational institutions of many developed countries are widely studying the benefits and innovative forms of using tablet PCs and stylus-based technologies [18]. In his work, J. Kromak explains that tablet computers contribute to the implementation of seven principles of educational practice:

- promote active interaction of participants in the educational process;
- encourage cooperation, that is, exchange of experience and working together;
- encourage an active attitude to learning;
- provide fast feedback;
- allocate time for the task;
- allow to communicate without restrictions;
- nurture a tolerant attitude to each participant in the educational process.

The above-mentioned principles are crucial for enhancing cognitive activity in the learning process, as compared to passive retrieval, which leads to the availability of high potential for tablets to improve the educational process due to significant changes and completely new aspects in the ways of interaction of all participants in the educational process. Despite its advantages, this technology is not yet fully recognized and widely used, especially in the field of foreign language teaching.

Tablet computers can be implemented into the process of learning a foreign language in order to improve and formulate the foreign language competence of future specialists of different fields. For this purpose, the work can be organized in pairs, groups and micro-groups of permanent and variable stuff, and individually (Fig. 4).

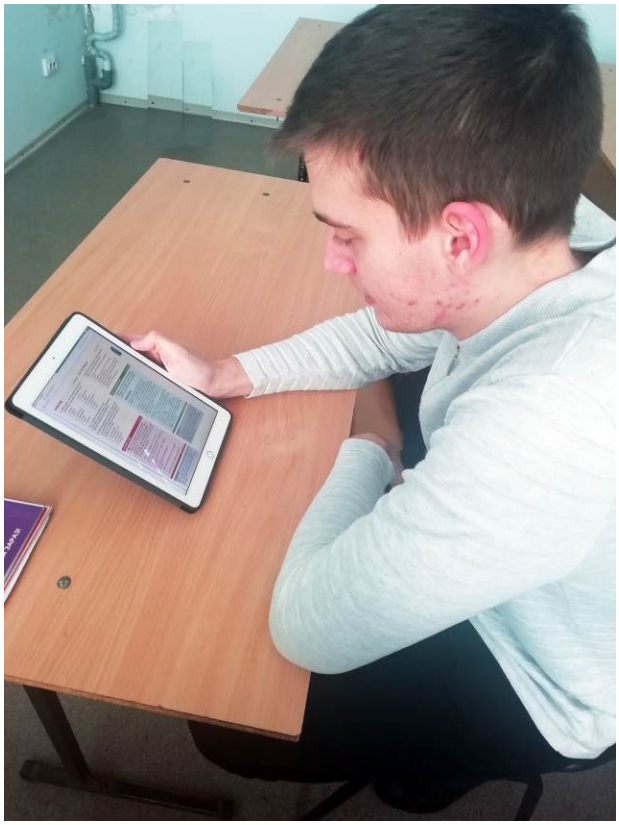

Fig. 4. Tablet PC use in the classroom.

For effective group work, students firstly receive plans describing the algorithm of group work, and then they organize the interaction and planning of activities by themselves. Tablet computers are used to provide the search of information while solving problems and act as the main tools for projects implementation.

To accomplish tasks set by the teacher, communication situations were developed in such a way aimed to provide a deep understanding not only of the new language material, but also the activation of professional knowledge that was previously acquired during the study of specialty disciplines. Such tasks are predominantly problem-oriented, and their

implementation is realized through a combination of individual and group work. Thus, students are trained in oral and written communication in a foreign language in order to develop the ability to build logical and reasonable answers, to conduct polemics and discussion, processing information from scientific and popular science spheres.

Approximation of training to real production situations, modelling of specific production processes effectively contribute to the interest in the study of disciplines. That is why the development of communicative competence by means of ICT was carried out not only on the basis of the fulfilment of educational tasks, but also tasks of a professional nature both in the classroom and at the enterprises. In this regard, the aspect of ICT application has considerably expanded and the role of computer technologies in solving the educational and production tasks has been strengthened.

Thus, studying the topic "Soil preparing machines", the future specialists in the agro-engineering field were offered a situation directly related to their future professional activity:

"Imagine you are working in a team of agricultural engineers at one of the farm enterprises. The enterprise, expanding its production, has a rented field area. Your task is to determine what plough model will provide the best soil preparation for cereals (the ploughing depth is no more than 30 cm, humidity is no more than 60% and slope of the field surface is no more than 10°. On the farm there are tractors of traction class 3 with an engine capacity of 150… 170 hp)".

According to the task, students have to consider the main plough types that can be used under the given conditions, analysing their advantages and disadvantages, agree on one best model, and present their decision in the form of a mini-presentation to the audience with further discussion. In this case, the tablet acted not only as a tool for finding and selecting information, but also for creating the project presentation itself. They are also able to review material given by the teacher, use additional online materials, make the necessary calculations, and create their own slides. Taking into account that each student has its own tablet, all the tasks are shared among group mates so that each member of micro group tries to present the most appropriate plough model, trying to prove his opinion to other team members, and after selecting one model, the micro group participants work together to successfully present the project to the audience.

Thus, the use of tablets helps students to present and share their thoughts, participate in discussions, create illustrative material to express their ideas as clearly as possible. This type of work contributed not only to mastering independent educational activities in computer technology, but also to organize productive communication between team members, creative development and the development of communicative and professional competences.

4 The integration of graphics tablet technology into foreign language learning process

Thanks to innovativeness and technical features, graphic tablets have long established themselves both among inexperienced users and among professionals in computer graphics and digital photography. But, in addition to the usual tasks that perform this kind of device on the desktop (for example, to replace the mouse at work), the functions of tablets today are actively used for other purposes that are unusual in the traditional sense. Thus, educational process can be significantly enriched by the presence of graphic input devices such as graphics tablets in the classroom.

A graphics tablet is a computer input device that enables a user to hand-draw images and graphics, similar to the way a person draws images with a pencil and paper [19]. The graphics tablet consists of a flat surface and a stylus or a pen, which can be used to produce free hand drawings or trace around shapes. The graphics tablet technology works due to the principle of absolute positioning: each point on the workspace corresponds to a certain point on the screen. Therefore, in order to move the cursor, it is enough to bring the pen or stylus to the corresponding area of the tablet. At the same time, it is not necessary to touch the surface of the working area: the tablet determines the location of the pen located at a distance of 1.5-2 cm from its surface. Thus, controlling the cursor with a pen requires a small number of movements and provides very high accuracy of actions.

Graphics tablets give teachers the opportunity to adjust their teaching to the unique needs of each student. Thanks to the convenient display, teachers are able to perform all the necessary manipulations, download files from the Internet and access all the necessary training materials even from previous classes. Such technologies, due to the fact that writing is carried out directly by an ergonomic pen or stylus directly on the display, make it easy to integrate students' ideas and comments into educational materials, using spontaneous notes, drafts and comments on the screen.

During the lecture, the author has practically no need to stand at the blackboard – a wireless graphic tablet allows the teacher to be anywhere in the classroom (though no more than 10 meters from a computer with a Bluetooth receiver). This allows teacher to monitor how students outline the learning material, even in the last rows of the classroom [20].

The implementation of graphics tablet technology into the process of studying foreign languages makes it easy to visualize learning material, stimulates student engagement and collaboration, supports distance and blended learning programs.

For example, while studying the topic "Tractor parts", students can work in micro groups or individually in order to describe the main principles of work and the structure of tractor main parts, visualizing them with the help of graphics tablets (Fig. 5.). Thus, they should accurately complete an illustration or scheme of particular tractor part and give a brief description of its

peculiarities and principles of operating. All of the data is saved on their laptops and sent directly to the teacher's computer or interactive board. In such a way student revise already known material, make the necessary notes and do sketches on their own in order to prepare a detailed description. After the work on the task is completed students should present gained results to other students and participate in the discussion, which positively contributed to the development of their foreign language communicative competence.

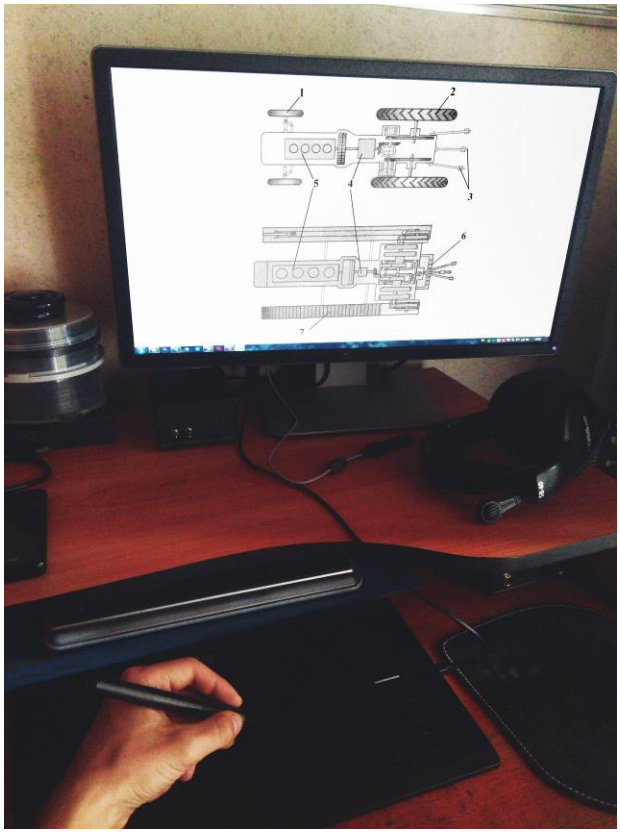

Fig. 5. Tractor sketches made by students.

One of the most important advantages of the graphics tablets is their application independence. It is not just tied to being used within a specific graphics application like Adobe Photoshop or Corel Draw. Students can choose the most convenient and appropriate software by themselves. On the other hand, both teachers and students need special training on working with graphics tablets and spend a great amount of time on practice.

5 The influence of ICT on the process of learning English for specific purposes: results of conducted research

For the purpose of the research the data received, after several surveys among TSATU students had been carried out, was analysed. The research has been conducted in two groups – experimental and control, including 45 and 44 students respectively. Before the experiment both groups had been taught by the same methods and assessed with the same materials. The experiment had proceeded through several stages. At the diagnostic stage of the experiment, the entry test (reading, writing, speaking and listening) had been done by the students:

- to test the level of reading skills, the participants had been asked to read the professional texts without vocabulary and complete the reading comprehension task;
- to test the level of writing skills, a lexical and grammar test and writing a letter to foreign partners or the general manager of the company, etc., had been performed;
- to test the level of speaking skills, monologue and dialogue speech had been evaluated within professional topics. During the testing, not only the content of communicative interaction had been taken into account, but also lexical and grammatical features of speech, application of socio-cultural knowledge;
- to test the ability of comprehension the job-related texts, listening the authentic audio materials had been carried out.

All students had been evaluated according to the European Credit Transfer and Accumulation System (ECTS) grading scale. Those ones who had Grade A are represented in group "Excellent", Grade B – "Very good", Grade C – "Good", Grades D and E – "Satisfactory". The results of the experiment are shown in the Fig.6.

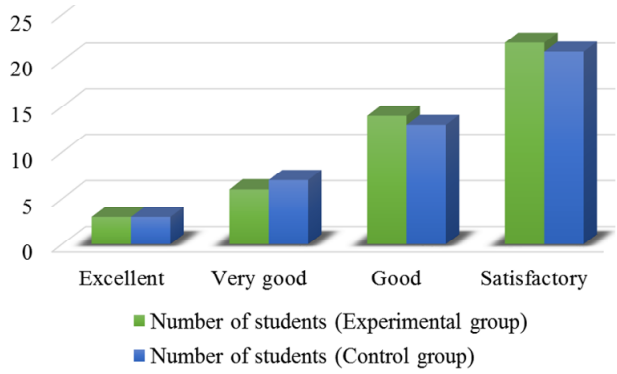

Fig. 6. The results of the entry test at the diagnostic stage of the experiment.

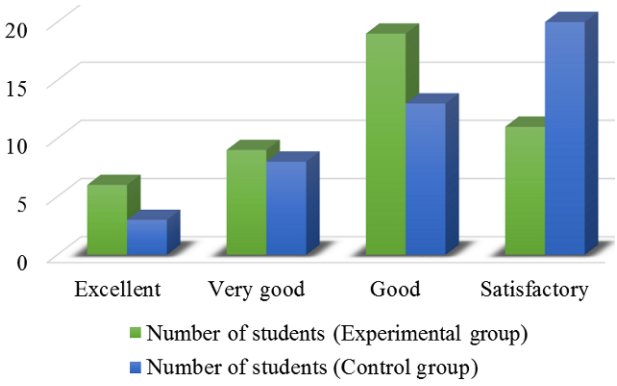

Fig. 7. The results of the control test after completing the experimental training.

On the next stage ICT had been implemented into the process of learning the course of English for specific purposes. The ESP class in the control group included

the same topics as in the experimental group, but teaching methods and materials remained traditional and unchanged.

The control test has been performed after completing the experimental training. In order to achieve the most accurate results, the data obtained in the experimental group have been compared with the results of the control group. After processing the obtained data, it became obvious that ICT have contributed to the development of the professional communicative competence at high level and positively influenced the quality of knowledge gained while learning the course of English for specific purposes. All obtained data can be seen in the Fig. 7.

Conclusions

The conducted research makes it possible to stress the necessity of information technology implementation into the process of learning foreign language for specific purposes. The basic principles of modern methods of foreign language teaching are: movement from the whole to the individual, student orientation (learner-centered lessons), purposefulness and content of the lessons, their focus on achieving social interaction, integrating the language and mastering it with the help of knowledge from other fields of science.

The realization of these methods today is almost impossible without application of different technological means such as computers, laptops, whiteboards, tablet PCs and graphics tablets. In foreign language classes, these ICT tools provide a greater opportunity to develop students' educational, informative and communicative competences which are of high demand for sustainable future development. Thanks to information and communication technologies, teachers can solve a number of didactic tasks, namely:
- to develop skills and abilities of reading, writing, listening and speaking, using the materials of the global network;
- to replenish students' vocabulary;
- to form a strong motivation for students to learn a foreign language.

The use of these information and communication technologies provides greater flexibility of the learning process, active interaction between the teacher and students, as well as between the students themselves, openness, mobility and prompt exchange of information.

It should be mentioned that the use of computer technology in the learning process affects the growth of professional competence of teachers. It contributes to a significant increase in the quality of education, which leads to the solution of the main task of educational policy.

Analysing the experience of using ICT in ESP lessons, we can confidently say that the use of information and communication technologies allowed:
- to conduct lessons at a high aesthetic and emotional level (music, animation);
- to increase the effectiveness of the lesson;
- to provide positive motivation for learning;
- to increase the volume of work performed in the lesson in 1.5 – 2 times;
- to provide a high degree of differentiation of education;
- to improve knowledge control;
- to provide access to various reference systems, electronic libraries, other information resources;
- to rationally organize the educational process.

The experimental data confirmed the effectiveness of the information and communication technologies implementation into the process of ESP learning. The results obtained during the experiment indicate that the students of the experimental group, in comparison with the students of the control group, have positively changed the level of foreign language professional competence, motivation to learn a foreign language, formed a positive attitude to self-education and self-realization.

The prospect of further research is seen in the conducting experimental studies on the practical application of other types of ICT in the English language learning process in order to select the most effective ones.

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Blended learning for sustainable education: Moodle-based English for Specific Purposes teaching at Kryvyi Rih National University

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Abstract. The article deals with the experience of implementing Information Communication Technologies (ICT) into ESP (English for Specific Purposes) teaching and learning. Informatization and application of innovations in education has resulted in emergence of e-learning. While Moodle is one of the most popular Learning Management Systems (LMS) and it enables and facilitates the shift to the student-centered education, the article highlights its implementation and adjustment to the specific nature of teaching and learning languages for specific purposes at Kryvyi Rih National University. The article touches upon reasons for applying Moodle to language teaching/learning and its advantages as a complement to the traditional face-to-face, or classroom, mode, thus combining them into what is referred to as blended learning, or b-learning. Both the teachers and learners interviewed demonstrated positive attitudes to using the platform in their practices. Besides, the article touches upon Moodle-based opportunities of managing the content and monitoring students' activities both in general and by individual courses. As Moodle is a web-based distance education platform not initially developed for language learning, the article invites discussion on advantages and disadvantages of its application to teaching/learning foreign languages and finding out which factors may allow language teachers and learners to boost its use and reach the set goals.

1 Introduction

The concept of Sustainable Development forms the foundation for the world community's actions aimed to preserve our civilization for generations to come. Sustainable development is based on mutual understanding and interaction of nations, which is impossible without knowing at least one foreign language.

Sustainable Education or Education for Sustainable Development allows every human being to acquire the knowledge, skills, attitudes and values necessary to shape a sustainable future. It requires participatory teaching and learning methods that empower learners to change their behaviour and take action for sustainable development [1]. All this requires a common language, a lingua franca, to facilitate any kind of international communication in the sphere of sustainable development.

The post-industrial society is characterized by a high degree of informatization and application of innovations impacting every area of human life, education being one of them. Creation of computers and the Internet have provided teachers and learners with both learning materials and tools that facilitate knowledge acquisition and retention and resulted in wide implementation of Information and Communication Technology (ICT) into education [2, p.38].

Information and Communication Technology has evoked new approaches to training as a whole [3, 4] and to teaching foreign languages in particular and resulted in emergence of e-learning – web-based distance education platforms offered by Learning Management Systems. These multi-purpose software applications complement the current learning practices combining traditional (classroom-based learning) and virtual (e-learning) formats of teaching/learning any content including foreign languages. The combination of the kind is often referred to as blended learning. Among a variety of free and commercial e-learning systems, Moodle is a free and open source e-learning software platform [5, p. 51].

Though originally developed for distance learning, Moodle offers helpful and motivating tools for teaching/learning foreign languages both online and in class, thus increasing efficiency of independent and individual work. Multiple combinations of Moodle elements (test, wiki, forum, chat, glossary, assignment etc.) enable teachers to settle didactic and learning problems and tasks and reach particular goals. Distance learning is associated with its accessibility to many people 24/7.

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Over the last few decades, foreign language instruction has been one of the leading educational areas in which technology is playing a salient role. It should be noted that the more technologies are incorporated into foreign language instruction, the more opportunities are provided for teachers and students to become globally connected and educated. Modern technologies are an integral part of today's ESP training giving students a break from traditional activities, yet reinforcing their language learning skills through the so-called language immersion defined as the process of students' plunging into the foreign language environment by means of either excluding or limiting the use of their mother tongue [6].

Learning Management Systems are used by education specialists to create and teach courses in distance education environment. In blended courses, classroom lessons and online courses are used together and this flexibility increases accessibility of learning activities and opportunities for interaction [7, p. 597]. Moodle is an open-source learning management system that allows users to create online courses. It is easy to install and use; there are hosted or one-click options available. Being a kind of ICT, it leads to a new quality of instruction and reflects the modern tendencies in education by providing continuous access to learning resources according to the anytime-anyplace principle. Flexibility in learning enables learners to learn when they want (frequency, timing, duration), how they want (modes of learning), what they want (learning content) and where they prefer to learn. Besides, the "anytime-anywhere-anyhow" learning is characterized by loosening logical and didactic constraints [7]. The Moodle platform offers time and place flexibility as an essential advantage of the innovative teaching-learning toolkit as learning activities can be adjusted to meet learners' specific needs constrained by busy schedules, lack of time, psychological and other issues. The target language competencies can be practiced in the environment that closely resembles the real-life one or even in actual communication situations. The platform provides various language support including vocabulary and grammar references and training, speech patterns, etc. It is also a new inventory for developing a human of the new information society capable of mobile-assisted life-long learning.

Theoretical and practical aspects of use of ICT in education in general and in teaching/learning in specific areas are widely covered by scientists and practitioners [8, 9, 10, 11].

Much attention is also paid to LMS as they produce a significant impact on the educational process [12]. As software systems that combine different tools used to "systematically deliver content online and facilitate the learning experience around that content" [13], LMS can complement traditional classroom-based formats, resulting in b-learning.

Among the variety of platforms providing tools for virtual education, Moodle is one of the most popular LMS in the world with 226 countries applying them for educational purposes [14]. Not initially designed for language learning, Moodle, however, is globally used in this field, adding to enhancement of language acquisition. Yet, potential of this platform in teaching/learning languages does not receive sufficient coverage in national scientific literature.

The research proved efficiency of the Moodle system application to teaching and learning foreign languages at higher educational institutions of Ukraine taking the practice of Kryvyi Rih National University as an example. The objectives of this research include finding out what features of the Moodle system are used by the English teachers of the University, what are advantages and disadvantages of using Moodle features and working out some recommendations to further wider implementation of the system. The research aims at studying involvement of the University language teachers and their methodology through understanding and interpreting their opinions in terms of Moodle integration in their everyday teaching practices.

2 Methodology of the research

The conceptual framework of this research is based on conceptualization of efficiency of using the learning management system Moodle for University teachers and students learning English as a second language for specific purposes. The researchers utilized cluster sampling in the study.

The number of participants in the research made 13 full-time language teachers of Kryvyi Rih National University, Ukraine, training future engineers for a variety of industries including mining, economy, management, IT, electric engineering, machine building, ecology, etc. They were all interviewed on the issues relevant to the present research. The research instruments involved application of questionnaires and interviews.

3 Results of the research

In Ukraine, main trends in forming higher engineering education involve changes in the structure, organization, forms and methods of training that correspond to the prevailing trends of the world educational system. Changes in the training structure and content call for applying both conventional and innovative forms and methods of foreign language learning and teaching accompanied by up-to-date technologies.

Implementation and active application of ICT to education is one of the priorities required for its reforming. Despite difficult economic conditions, most Ukrainian higher educational institutions, especially engineering ones, are provided with equipment for introducing online learning technologies into their training process [15, p. 141].

The Foreign Languages Department of Kryvyi Rih National University is intensively using innovative technologies in the training process, this being supported by the following facts. The University provides a 24-hour access to the Internet (including the wireless one) for its employees and students. Most teachers, lecturers and students of the University are computer-literate.

Analysis of the current facilities of Kryvyi Rih National University and students' polling allows us to conclude that provided educational and reference data are sufficient enough to ensure a successful training process in terms of foreign language teaching and learning as the Foreign Languages Department has three specialized multimedia laboratories at its disposal, most students have their own digital devices and an access to the Internet. There is evident lack of face-to-face hours of English training (68 hours per year for 1-2-year courses with the exception of a 3-year course for students majoring in software development (a 3-year course, 204 contact hours) and a 4-year course for foreign economic activity management students (340 contact hours)). Application of ICT creates suitable conditions for students training as there is a constant access to training resources any time in the user-friendly environment).

The virtual training environment on the learning management platform Moodle was introduced several years ago. Since then, Moodle has been used more and more intensively by both students and lecturers. A lot of authentic and didactically-enriched materials have been accumulated, that providing the basis for a variety of authors' training courses. Within the courses, teachers can share materials, manage communication and set up activities.

While designing the courses, the developers used special modules of Moodle in support of learning foreign languages. The courses are designed on the basis of sound learning principles tailored to aid the development of practical skills such as listening comprehension skills (*European Integration through Education; Language Skill assessment; Examination Videos; Phonetic Skills Development*); reading and writing skills (*Business Law; Tests for IT Students*); speaking and specific terminology (*English for Mining Engineers; English for Mechanical and Electrical Engineering; Metallurgical Vocabulary*) [16].

Moodle for learning English is flexible enough to support innovative blended teaching methods. The given approach is of great value for both students and teachers. Students are engaged into doing independent or solo work at any time convenient, while teachers are able to control and check students' works without auxiliary workload. The platform provides an opportunity to develop online interactive courses that boost students' creativity, outlook and cognitive abilities, thus enhancing training outcomes.

Moodle implementation at Kryvyi Rih National University included two stages. On the first stage, the University lecturers studied possibilities of the virtual training environment and developed a number of courses for first- and second-year students.

The stage included:

- substantiating theoretical and methodological principles of the research;
- developing a programme of the research;
- determining the aim, objectives and methods of the research;
- developing and systematizing training electronic courses and testing sets;
- updating available methods of using ICT in foreign language teaching and learning.

In practice, the University English teachers who used Moodle on a regular basis in their instruction covered the following system features:

- creating and managing course content;
- developing assignments, exercises, and tests;
- providing students' workgroup and peer review;
- providing students' journal and document submission;
- providing access to online quizzes, surveys, videos;
- assessing students' knowledge and providing grades and ratings.

As for creating and managing course content, it appeared to be the most widespread activity as numerous materials, exercises and tests were uploaded by means of this Moodle feature. This is particularly applicable to providing listening assignments so that students can visit anywhere and anytime and practice their listening skills online. Students are encouraged to use embedded glossaries as many of them have a very low knowledge of English vocabulary. It eliminates the necessity to provide students with loads of printed materials and saves a lot of teachers' time and efforts. If students come across comprehension problems in their reading or listening activities, they can look up the necessary vocabulary by using glossary links anytime.

Peer review is a good opportunity for students to learn something new and consolidate their own knowledge and skills through commenting on other students' works and analyzing their mistakes. Teachers also treated online quizzes and surveys as a good chance to make a difference in their everyday instruction routine. Students' grades and ratings encourage fair and transparent assessment of their success in foreign language learning.

The mentioned work continued on the second stage. Accumulated experience allowed developing courses by integrating authentic or didactically supported multimedia resources and a variety of communicative learning activities for graduate and postgraduate students, varying task types and their character and making them more interactive and relevant to students' needs. Besides, the e-tools of the Moodle platform are applied to monitoring students' results through active communicative teacher-student or student-student contact (by using e-mail, forum, chat) and controlling students' learning activity by means of feedback, evaluation and statistics. All this determines opportunities to increase quality of provided resources as well as assessing efficiency of the blended learning process. Obtaining speaking skills is critical in learning foreign languages. Thus, when we run out of discussion time in a face-to-face session, Moodle forum is used to continue online. Student and the teachers spend time formulating thoughtful responses and dig into deep discussions. Moodle breaks courses into topics that form a structural pathway through all the materials studied providing blended learning. To fulfill these objectives, there were developed 16 courses on English grammar, vocabulary, country study, etc. for undergraduates, graduates and post-graduates of all specialisms [16] (Fig. 1, 2).

Fig. 1. A fragment of the list of courses in Moodle

Fig. 2. A fragment of the *Language Skills Assessment* course

The scope and results of Moodle potentials implemented in Kryvyi Rih National University for arranging students' individual and solo work are summarized in Table 1.

Table 1. The scope and results of use of Moodle for arranging students' individual and solo work.

Stages	Content	Results and reporting
I	- development of required and elective courses (grammar, lexis, country studies, etc.) for 1- and 2-year students of all specialisms; - practical testing	*Results:* - development and accumulation of author's courses and the tests base; - arrangement of the available archive of training resources; - ICT-based updating of current teaching methods *Reporting documents:* - printed log-files (with Moodle-based activity duration, completed tasks, etc. indicated)
II	- wide application of the developed courses to learning and its quality monitoring; - development of courses for graduates and postgraduates; - further test base development	- application of new Moodle-generated teacher-student, student-teacher-student, student-student modes of interaction enabling novel teaching/learning communication forms; - attendance monitoring and students' work control; - enhancement of the test base (resulted in determining the complexity threshold and fixing individual and group problems) *Reporting documents:* - the system weblog; - the printed test base and its analysis; - course attendance reports

So, Moodle provides teachers with a feature enabling them to analyze students' activity in Moodle both in general and for each course and thus introduce necessary adjustments as for relevance of the activity, its complexity, degree of the material digesting etc. that is, a teacher can monitor frequency of the students' visits, detect problems and decide on ways of the problem settling and directions of further work. It should be noted that students also have access to their grade records, this producing a significant motivating effect. Fig. 3, 4, 5, 6 present various types of reporting in Moodle.

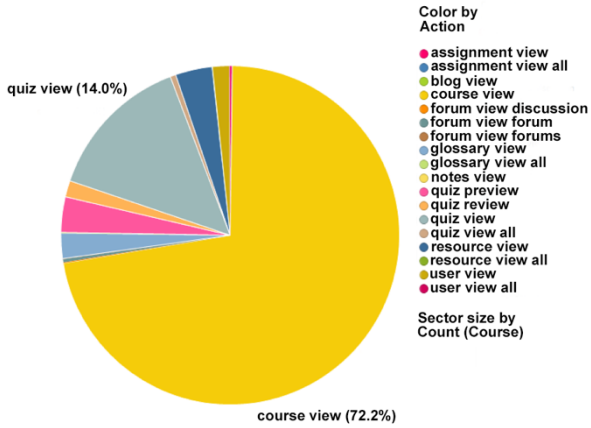

Fig. 3. General analysis of students' viewing resources

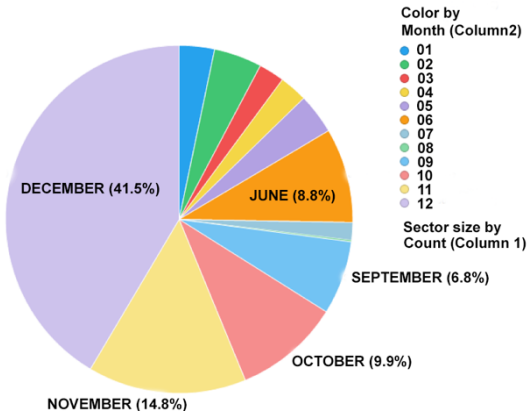

Fig. 4. Students' activity by months.

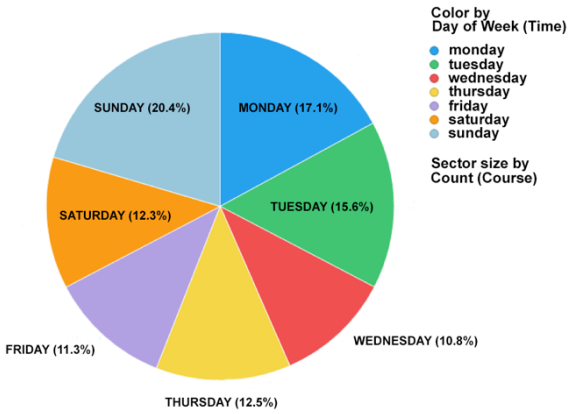

Fig. 5. Students' activity by days of the week.

	First name / Surname	Email address	State	Started on	Completed	Time taken	Grade/10.00
	Student2 StFLD Review attempt	stud[redacted]net	Finished	2 December 2019 3:54 PM	2 December 2019 4:06 PM	12 mins	9.00
	Valerii Krivoruchko Review attempt	kryvc[redacted]@gmail.com	Finished	2 December 2019 3:54 PM	2 December 2019 4:06 PM	11 mins 21 secs	9.00
	Maksym Kruppa Review attempt	Max7[redacted]mail.com	Finished	2 December 2019 3:55 PM	2 December 2019 4:05 PM	10 mins 4 secs	0.00
	Ivan Bohatsky Review attempt	ivar[redacted]mail.com	Finished	2 December 2019 3:55 PM	2 December 2019 4:04 PM	8 mins 7 secs	9.33

Fig. 6. Test results.

4 Conclusions

Analysis of new forms of training activities in case of the Moodle platform use enables the following conclusions. Implementation of ICT in higher education is one of the priorities of its informatization. The Moodle platform has some evident advantages (time-space independence (the anytime-anyplace principle), convenience and flexibility, the student-friendly environment to motivate and boost learners' self-esteem, etc.). It is an effective supplement to conventional forms of training organization that encourages foreign language learning.

According to conducted interviews of the English teachers of Kryvyi Rih National University engaged in the research, the uttermost and most evident advantage of Moodle application to foreign language teaching and learning is boosting student-centered learning. Students are able to obtain a huge amount of language practice using online materials either authentic or developed by their teachers. They can choose the training content and supporting activities according to their own interests and language proficiency levels. Speaking about the anytime-anywhere principle of the Moodle system, it provides almost limitless opportunities for studying languages both in and out of class. This principle is well supported by Moodle course convenience of control and administration as teachers are viewed as course developers and administrators.

The file types offered by the platform enable increasing future engineers' cognitive activity by presenting training materials in a variety of ways supported by a great amount of reference sources (grammar explanations, templates of project tasks, presentations, reports) in PDF. PowerPoint presentations are applied as both teaching tools and tasks for students' independent and solo work. Thus, students are able to improve their knowledge and skills of their future specialisms through being exposed to advanced developments in engineering presented in English.

The Moodle platform is also applied to forming professional skills through second language learning in terms of professional English of specialisms with its further application as a means of business communication and intercultural exchange.

The research has proved that Moodle enables incorporation of conventional and innovative forms and methods of training (b-learning) being an efficient tool of sustainable foreign language teaching and learning. It is also an efficient tool to make university language training more cost- and time-effective. Teachers can save time, paper and other resources by using the platform as they are able to create and store their materials online. Mobile devices such as netbooks, laptops, iPads, tablets, smartphones, digital cameras, mp3-players, personal digital assistants and electronic books have become very widespread, especially among young people. They are incorporated into modern ESP classroom and become a subject for both research and sustainable practice in technology-enhanced language learning.

However, in spite of numerous advantages of using the Moodle platform, there are also some disadvantages of using it in b-learning. The drawbacks of applying the Moodle system in Ukrainian higher educational institutions can concern some technical, instructional issues and efficiency of learning results. The technical problems arise from instability of the internet connection, lack of reliable equipment and computer-literate staff. Unfortunately, only 8 out of 13 English teachers are currently using the Moodle platform on a constant basis. The instruction problems are caused by evident lack of training and time required for teachers to get acquainted with the digital platform as some features are reported to be either irrelevant for foreign language teaching or quite demanding for both teachers and students to master. Yet, this powerful tool of training management is not used in Ukraine as widely as it should be, in particular concerning foreign language training, this making the basis for further theoretical and practical investigations into Moodle and its use for blended learning.

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Developing English presentation skills as a component of collaboration competence for sustainable development

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Abstract. The paper deals with the problem of teaching non-linguistics students English presenting as a component skill of collaboration competence. Students' considerable reluctance to take up this type of creative activity and to present their ideas in front of their colleagues is a serious obstacle to develop their communicative abilities necessary for prospective leaders of the 21st century in science and industry. The results of the survey of Machine Building and Computer Science students as to reasons for their disinclination to create presentations are presented. The strategy for overcoming students' unwillingness and building their presenting confidence are given. The example of implementation of a task for strategic thinking for sustainable development within the discipline 'English as a foreign language' is given. The aspects and stages of effective online presentation editor application for teaching English presenting are analysed. The results of students' choice of five presentation tools are included. Three prospective online presentation makers are analysed and their utility for creating and giving English presentations are studied. It is stated that the most promising online tool is Prezi since it offers prepared professional quality features and incites developing and incorporating personal creative ideas through bright and uncommon visual means.

1 Introduction

Abilities to learn, to deduce new ideas from current data, to produce new knowledge and to share it in order to encourage new research are outcomes of the modern university study. Universities must "play an increasingly important role in helping students become responsible and active citizens, with a clear vision of the importance and future challenges of sustainability" [1]. According to the Strategy for Education for Sustainable Development developed by the United Nations Economic Commission for Europe (UNECE), education is a prerequisite for achieving sustainable development. It is essential to equip people with knowledge of and skills in sustainable development, making them more competent and confident [2]. In order to undoubtedly reveal own potential as a valuable asset, a global thinker and a prospective change maker, a present student should be taught adopting an alternative educational approach which includes in addition designing and presenting sustainability projects. The implementation of the sustainability principles into curricula can provide students with all necessary knowledge and skills. But the extent to which this implementation is possible and ranges of disciplines involved are being considered by most universities separately. Since English is the language of global communication, this discipline should inevitably inculcate sustainable development ideas in students. It is crucial for prospective leaders in science and industry of the 21st century to be able to clear their communicative intention and achieve communication goals in English. Ukrainian graduates in Engineering and IT specialities should be able to help reduce national and global poverty, connect people and enhance common IT competency, create inclusive societies through multinational engineering projects. Ukraine has considerable potential for rapid development of partnerships with the countries of the European Union and in the Northern Hemisphere in the fields of sustainable economics and production. Today, demand on qualified human resources outweighs importance of available material resources in most key industries and IT sphere. The interest of foreign companies in Ukrainian employees is undeniable. However, one of the basic requirements for a professional-to-be with impressive career prospects is according to the study of V. Osadchyi and S. Symonenko [3, 4] advanced English communication skills. Forming communicative skills and command of English are preconditions for educating professionals-to-be as global citizens for sustainable development.

Good command of English supposes demonstrating the level of confident usage of the employer country language and experience in professional and business sphere communication in order to carry out communicative intents as part of the collaboration sustainable development competence. Collaboration (interpersonal) competence ensures that "professionals have an open ear (and language competence)" [5], are

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able to map different perspectives and values and facilitate dialogue. Against this background, formation of English communicative competence of students in the educational process at universities is a prerequisite for their further professional growth and competitiveness worldwide. The collaboration competency skills like ability to present themselves, their ideas and debate on professional issues, to speak out in front of colleagues, to listen actively and to inquire soundly can and should be trained during university studies. Namely these skills are most effectively developed and deepened through giving a presentation.

The analysis of recent scientific and publicist sources indicates also that the preconditions for creative intellectual activity in a foreign language, for motivating students for thorough preparation for foreign language reporting and presenting (accompanied by audiovisual means), and the problem of overcoming psychological and language barrier remain insufficiently explored.

The purposes of this article are to develop an integrated approach to gradual formation of positive students' perception of preparing a presentation, to give an example of implementation of sustainable development issues into a problem task, to present ways of teaching students creating and editing English reports accompanied by online presentation and to analyse particular editors' suitability for teaching students creating English presentations.

2 Verbal communication as an educational skill of the 21st century and a component of the sustainable development competency

The term ‚21st century skills' is shifting and blurred as according to different sources it includes a wide range of skills, knowledge, character traits and work habits, associated with 21st century trends and professional demands.

Awareness about the crucial role of communication skills and the necessity for their inculcation in students to prepare them for becoming today's highly collaborative, innovation-focused workforce brought teaching those skills into foreground of educational field.

In 2006, the program P21 Framework for 21st Century Learning was first published and has been continuously updated [6]. It is a model for incorporating 21st century skills into learning developed by the alliance of the US Department of Education, businesses (including Apple and Microsoft) and educational organizations. The Framework rests on core academic subjects (like languages and foreign languages) for teaching life and career skills, learning and innovation skills, and information and media skills. The P21's research-based 4C's and most promoted activities are Creativity, Critical Thinking, Communication, and Collaboration.

Bobbi Kurshan, an education entrepreneur and an expert on how innovation and technology are transforming teaching and learning, notes that the term '21st century skills' is often used in educational circles to refer to a range of abilities and competencies including problem solving, communication, collaboration, creativity and innovation [7]. Kurshan also refers to the P21's Frameworks for 21st Century Learning, where she sees her vision of skill list augmented and split into learning and innovation skills (creativity and innovation, critical thinking and problem solving, communication, collaboration) and information, media and technology skills (information literacy, media literacy, ICT literacy). The overlap of both classifications is the necessity of educating in the 21st century a good communicator able to use all the variety of means to interact with people around the world and flexible about rapid changes in information technology tools.

The Glossary of Education Reform [8] lists 55 items as Skills of the 21st Century, of which we are going to refer to following skills:

1. Critical thinking, analysis, interpretation, synthesizing information
2. Research skills and practices
3. Creativity, innovation, personal expression
4. Oral and written communication, public speaking and presenting, listening
5. Information and communication technology (ICT) literacy, media and internet literacy
6. Scientific literacy and reasoning.

The mentioned before competencies in education for sustainability or competencies for Sustainable Development (ESD) were developed by UNECE. ESD raises awareness of the complexity and dynamism of issues. It also plays a key role in making sustainable development understood and in ensuring it is applied in specific ways. ESD aims to plan specific sustainable actions at all educational levels, favouring the development of competencies that allow people to think about their actions. According to School of Sustainability, ESD goals include: Forming Systems Thinking Competence, Futures Thinking (Anticipatory) Competence, Values Thinking (Normative) Competence, Strategic Thinking Competence and Interpersonal (Collaboration) Competence [5]. Summarizing the concept presented above it should be stated that individuals as part of society must have the power to act in complex situations in a sustainable manner.

The mentioned above skills are closely connected to abilities to achieve communicative intention, to build long-term rapport and consensus and are in our opinion referring to verbal communication as a crucial skill underestimated in Ukrainian education. Nowadays, students tend to communicate using technology, and most of young people are characterized as digital native or media fluent in respect of online socializing. Nevertheless, communicating is more than sharing information and assessing it according to your likes and dislikes. Communication includes personal interaction in the first place but suggests that skills of application of supporting and accompanying means for personal interplay are going to be continuously improved. The examples of such advance are mastering blogging, communicating through video, creating a visual product.

3 Presenting in English as education aspect

Within the Education for sustainable development strategy an English course goals expand and suppose [9]:
– working towards making changes in training which leads to increased attention and focus on discipline. We refer to this point by H. Kanuka as increased students' motivation and interest in compulsory and optional learning tasks;
– using technology in ways that create openings. In our opinion, the multi-disciplinary approach is welcome since IT and foreign language synergy enhances outcomes in both disciplines;
– supporting informal learning. Engaging students in creative tasks, in international social projects, encouraging their initiative in form and venue choice is in our view sensible;
– achieving understanding through the use of diverse instructional methods. We would recommend supplementing traditional training techniques with innovative ones, e.g. accompanying a theme scrutiny with application IT tools).

Effective presenting is a multi-component learning goal which should be represented in both modes – within classroom activities and as an integral part of students' independent work. Introducing media education, developing media literacy and creativeness, formation of English media competence, and information technology application at English classes overlap one way or another in training of specialists of non-linguistic specialties. Within the academic disciplines 'English' or 'English for specific purposes', no teacher can guarantee having attracted every student in their classes to giving performances in public. Exemplary public presentations by at least some non-linguistics students often remain an ultimate but promising and unattainable goal. It is therefore sensibly to begin verbal communication improvement in vocational training with instilling in students the basic presenting skills through involving them into creating a small volume captivating presentations on familiar themes and content accompanied by audiovisual media of their choice.

We refer to the concept of L. Milovanova [10] that the term 'presentation' in the context of vocational training in higher education is not just giving a speech in front of an audience with the purpose of persuasion or inducement. It is an act of interpersonal communication, the success of which depends on the level of orator's skills in speaking and communicating. Consequently, a reported text for training goals does not have to be difficult because of the fact that it will be the subject of communication in a foreign language – discussion, dialogue and both criticism giving and accepting. The theme should be disclosed in such a manner and through such speech and visual means that it is comfortable for perceiving and feedback producing by well-informed or at least familiar with the theme audience.

Regarding the mentioned above strategy, we consider the point of view by O. Karpova [11] controversial. O. Karpova insists on the presence of the high level proficiency in a foreign language (B2, CEFR) as a prerequisite for applying by students multimedia technologies while preparing a speaking assignment. In our opinion, even language learning beginners should try giving short presentations. In this way speakers can assure themselves in the possibility of achieving communicative goals through the combination of a simply-structured author's text with adequate audiovisual media.

From the perspective of B. Chivers [12], student presentations have as their main purpose the following aspects:
– persuasion (to join in, to choose the presented theme or the item, etc.);
– training (demonstrating functioning and principles of work of a device or equipment, demonstrating own skill level in working with equipment, sharing own knowledge and experience);
– instructing and studying (forming a broad skill set, looking into a specific area, considering the problem from different perspectives);
– informing (introducing new facts or data, providing a dynamic progress report);
– assessment by a teacher (a teacher can soundly assess whether the student has acquired the intended knowledge and skills).

In fact, most presentations are the result of a combination of the goals mentioned above.

The most accurate classification of presentation types based upon the ultimate goal as a key criterion is provided in our opinion by The Bob Pike Group [13], the educational consultant:
1. Informing
2. Skill formation
3. Progress demonstration
4. Promoting a product or a service
5. Decision making
6. Problem-solving.

However, we insist on the integrated approach to preparing a student presentation as a communication task at the very planning stage. Therefore, a student's performance is going to ideally demonstrate the achievement of at least two logically connected purposes from mentioned above. Considering mediated communication we analyse a student individual oral presentation as a study object, when a student uses software or online editor to create and give their presentation.

Obviously, skillfulness and confidence in English speaking in front of groupmates are rare in classrooms of Engineering specialities. Richard Zeoli's expert opinion is that 'some individuals are definitely born with this gift, the overwhelming majority of effective speakers have trained themselves to be so. Either they have received formal media training or they have delivered so many speeches that over time they've learned what works for them.' [14].

Carmine Gallo, a communication advisor, business communication expert and Harvard instructor appeals to teacher colleagues not to force students to just one presentation but to "give them opportunities to share

parts of their project or assignments throughout the school year and give them options on how to do so" [15].

Peter Hyman, School 21 cofounder, notes that 'oral communication skills must be explicitly taught like other core skills in school'. We completely support the vision of this skill profit for present generations within the sustainable development framework outspoken by Hyman: 'a well-spoken, confident young person will have occasion to use those communication skills throughout his or her life' [16].

Generalizing three mentioned above opinions, the strategy has been worked out – to start training students to make and give presentations on the examples of short, personally engaging and concise reports accompanied by innovative and prospective visualizing tools.

4 Ways of building students' presenting confidence

In the curricula of future engineers in the 'Machine Building' speciality, individual creative assignments are included in the independent work aspect in English as foreign language. There has been developed an online course for distant learning on the Moodle platform [16]. There are two presentations on the themes on students' choice from the fifth term syllabus content. Basing on lexical-grammatical material of the term themes a student must prepare a report on a topic related to studied units from their English coursebook. The report should demonstrate personal experience and viewpoint on the particular problem.

The practical goal of this student independent work type is to consolidate the studied vocabulary, the pedagogical goal is to expand students' world view by studying additional facts and carrying out the thorough analysis of authentic English sources highlighting the importance of sustainable development. The educational goal focuses on creating appropriate system of linguistic concepts for discussion leading in the formats of a plenary session or of a face to face discussion. It also aims at raising general etiquette rules and speaking culture awareness during the conduct of a controversy or while holding a debate. The developmental goals include formation of speaking skills and building performing confidence, increasing readiness for conducting discussions with numerous opponents, improving automation skills in software using for the visualization of the report (ideally, an editor with a particular foreign language interface).

English learners in their first term mostly look into individual creative tasks reluctantly. The first reason for lack of enthusiasm is that individual work format and presentation as the form of sharing its results in plenum is unusual. Secondly, presenting in the humanities supposes fluent speaking but Engineering and IT students often consider themselves insufficiently creative or trained for public performances. Most students are not eager to give presentations in English even in front of their not numerous groupmates.

To motivate students for the above mentioned types of independent work, a number of steps have been taken, the first of which was the survey on difficulties demotivating students. The survey involved 54 undergraduate students (2-4 years) of 'Machine Building' and 'Computer Science' specialities of Dmytro Motornyi Tavria State Agrotechnological University. First, the students themselves have given arguments for and against giving presentations in English in the panel discussion. The outspoken objections were generalized and formed into two groups. Group 1 was supported by 38 students and focused on lack of enthusiasm in respect of giving presentations in any discipline. Group 2 (supported by 43 discussion participants) embodied students' concerns about not being able to overcome difficulties arising during preparing a presentation in English.

The second step taken to persuade students into public speaking was the detailed analysis of their reasons above: the counter-arguments (like professional necessity to present agendas, designs, reports etc.) were presented and the effective measures (like additional training, group projects with participants' workload and roles reasonably divided etc.) were suggested.

Among the generalized reasons for their reluctance to submit individual creative activity in the presentation form (group 1) the students have named the following issues which the teacher has opposed respectively referring to the sustainable development strategies and 21st century skills crucial for professional growth in globalized job market:

1. Dislike of presenting in general. As a counter-argument to overcome the natural modesty the teacher offered examples of mini-presentations in everyday life, which students embody regularly (such as presenting a new device to friends or telling them a travel story).
2. Foreignness of public speaking to Engineering and Computer Science spheres. The teacher has listed numerous examples of an employee's tasks, such as presenting their own achievements during job interviews, presenting a project to subordinates, reporting on a completed assignment to customers, training new subordinates, instructing trainees.
3. Time-consuming preparation. To mitigate this problem, the teacher has offered a number of sources and Internet resources providing information on the topics that are being studied in a particular English course. The resources are classified according to themes and language reference levels. In addition, student independent work in the form of presentation is correspondingly assessed (scores for successful problem research and its visual representation, prepared speaking and skillful coordinating after-presentation discussion are twice higher than regular scores for class work.)

Among the reasons for their unwillingness to explore specific suggested themes (which can be applied to most topics in English courses in every study year) students have listed (group 2):

1. Lack of confidence in their English proficiency level. The teacher has offered and provided some advice and assistance in research material simplification, presentation text writing and speaking training – ensuring correct pronunciation and intonation.

2. Poor knowledge on the topic of the alleged report to be presented. An example is the theme 'Planning sustainable cities in the 21st century'. The theme is composed based on the worked over video material of the coursebook – Navigate (Oxford University Press) [18]. The short film demonstrates how increasing number of high-rise buildings in London changes the metropolis. Not only the horizon line change but also social aspects in the city are explored: new jobs and business blocks in a particular area appear as a result of large-scale building construction. The presentation theme is derived from the video but does not reflect it because it includes the sustainable development aspect for students' consideration and suggests an individual agendum. Students are encouraged to present their own perspective on:
1) increasing resource and energy-efficiency in the city where their university is located,
2) designing spatial arrangement of inclusive pathways and streets for women, children, seniors and persons with disabilities,
3) founding the necessity and location of urban economic and social facilities for empowering local communities,
4) accelerating switch to the accessible and sustainable transport system for all,
5) providing inclusive and accessible green and public spaces.

To help the students the teacher has listed a number of Internet sources that represent the sustainable development goals [19] and a civic administration website which soundly and closely represents the agenda, statistics and factual data. It can be the link to the city council website where the students can get familiar with the projects of building construction and the renovation plans and timing. Students can compose a complete report and visualize it with online editors or Power Point using the mentioned above data combined with presenting their own experience (convenience or inconvenience, sustainability and the inclusion level of their neighborhood) or comparing two quarters of the city (a block of single-floor houses with driveways and small gardens and newly built office buildings in the city centre), or making a proposal to change or to improve the urban design).

3. Too large volume of material that should be analysed and compressed. An example of such a topic is 'Preparing for public speaking' in Business English course – Internet resources offer a variety of links to extended text, graphic and video materials. To help the students, the teacher carries out a brief training on the principles of printed text compression. Through individual counseling and looking into a theme together with a potential speaker, the teacher supervises their designing a report outline on a specific topic.

4. The inability to include personal experience in the report. In this case, the teacher can offer the students to present their own point of view. For example, if the report 'The world's most famous achievements and world records' cannot demonstrate students' world famous success, it can be represented in the form of a rating with reasonable explanation of ranking each item in a particular place. The criteria could be the importance of the achievement for the sustainable development, for the mankind, or the scale of raised funds, or effort put into the record, future prospects etc.). Alternatively, students can list several activities in which they dream (or at least would like) to express themselves, as well as the reward, which they consider fair or valuable for themselves or for other people.

5 Teaching Engineering students creating English presentations with online presentation software

In case of excluding complexity of composing a text part, students have no objections to the submitted creative task form. None of 54 surveyed Engineering and Computer Science students of Tavria University has avowed lack of skills or a low skill level in using software to create a presentation as a report's accompanying visual component. Nevertheless, the mostly referred to means of visualization was Microsoft Power Point. Selecting visuals for designing slides to accompany the report is considered by the students the most interesting (and the easiest) stage in creative task preparation.

As an additional incentive to exert maximum effort to prepare a presentation, it is offered to familiarize students with online presentation editors with a foreign language interface. Among numerous benefits of online presentation editors over desktop software namely their novelty is one of the most captivating. Among the survey respondents, only two students have worked with one of the online editors (Prezi). It should also be noted that abilities of competitive software (Haiku Deck, PowToon, SlideShare, Slidebean, Prezi, Beautiful.ai, Canva etc.), and even the fact of their existence and popularity in the English speaking Internet environment was a real discovery for most students.

The goal of presenting within a group at classes includes training skills as both a monologue on the prepared materials and script, and spontaneous speaking, which is a prerequisite for preparing presentations of scientific research results at student conferences in Alma mater, and at conferences at other universities. It should be noted that the usage of online editors in the first phase (in their own student group) often stimulates students to a more creative text and visual representation, encourages more free manner when speaking (for example, when the statement or the applied visual tricks find groupmates' approval) and in dealing with discussion questions.

The second stage of presenting skill training takes place in a more sophisticated environment of science conference sections. Wide visual abilities largely become fundamental to transform formal research materials in a report text into innovative scientific solution in the course of speaking. Accompanied by an online presentation a scientific report can be presented understandably and, most importantly, captivating even for non-experts in a particular area.

To familiarize students with the English interface of

high-performance and unusually creative online editors a teacher has to conduct thorough preparatory work. Firstly, it is necessary to create atmosphere of eagerness and motivation to acquire new knowledge and skills in student audience. One of the options is to show a promotional video of a specific service for online presentations in which professional marketers have already collected the best abilities of the product. Another (equally effective) option is demonstrating a fascinating presentation of a senior student (who has participated in a scientific conference with a report accompanied by a 'non-standard' online-presentation). A teacher's promise to help everyone to learn how to create such impressive English products in the English-interface editors is a strong incentive for students.

Secondly, a teacher should make sure that the classroom intended for demonstrating online editor advantages is rigged with all the necessary technical equipment and devices. At the stage of introducing of operation and differences of online-editors from desktop software a teacher is going to need:

1) a computer with Internet connection, big TV or multimedia projector;
2) their own profiles of a registered user for each online presentation editor, which is going to be demonstrated to students;
3) various digital content (such as audio recordings, documents in different formats and different types of images) for current demonstrating of online editing;
4) handouts presenting keywords (as appropriate a wordlist) and a list of instructions.

Handouts are actually the third prerequisite for successful interaction between a teacher and students when investigating online editor utility. Handout cards or worksheets should contain lexical units required to work with any software ('open', 'add', 'copy' etc.) and the vocabulary only inherent in certain online editors (for example, 'style library' in the editor named PowToon, 'deck' in Haiku Deck, 'discoverability score' in SlideShare). After having done several tasks for expanding students' vocabulary it is reasonable to proceed to gradually familiarize students with online applications.

The best way to introduce the principle of operation of a particular online editor is giving live performance of online presentation editing. Using the prepared digital materials the teacher is explaining in detail their actions and commenting on the result in the foreign language. In such a way the teacher logs in to the working environment of each online editor aimed to be studied one after another. The teacher creates simple presentations under the same scenario or plan. It is sensible to demonstrate applying the most important functions (adding text or multimedia, formatting tables, zooming, customizing and turning slides) and interesting options specific to a certain online editor (for example, changing the font size with a very comfortable bar with a slider while previewing the result in the Slidebean online editor or zooming and rotating separate elements or whole slides in Prezi).

Having watched the editing and presenting processes with 5 different online presentation makers (Prezi [20], Keynote [21], Canva [22], Beautiful.ai [23], Haiku Deck [24]) performed by their teacher students have ascertained that it is quite possible to create a presentation online easily and give it more vividly and impressively. All 54 students having participated in the discussion mentioned above have stated their intention to try creating and giving presentations with online editors.

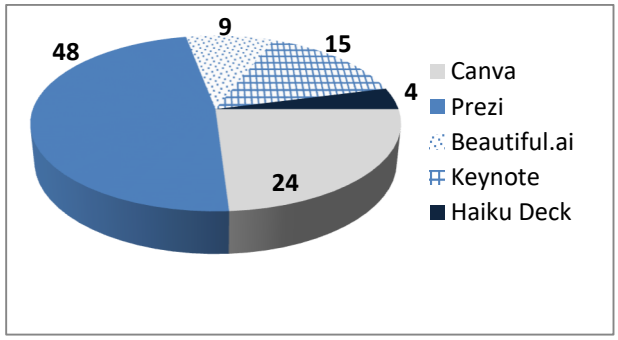

Fig. 1. The results of the survey on the most prospective online presentation makers for presenting in English.

Three web browser presentation makers of five have been chosen by students through a survey. The criteria for opting were user-friendliness, variety of editor features and outcome impressiveness. The results of the survey are represented in the diagram (Figure 1). The majority of students have opted for Prezi, Keynote and Canva.

The most effective and widely used PowerPoint alternative is a presentation tool named Prezi [20] – a web-based presentation software with more than 60 million users worldwide.

It is especially popular with entrepreneurs und educators thanks to customized pricing and follow-up policy. However, only paying subscribers have the option to assign privacy rights. Anyone can find and view prezis from free accounts.

Providing a wide range of completely free functions (there are upgrades a user can pay for to unlock additional features), Prezi gradually gains more premium subscribers offering some unique features like motion, zoom, and spatial relationship. One large canvas is a scalable background which allows zooming various frames or visuals of the canvas and therefore emphasizing the presented ideas effectively. A user can add their own content to communicate ideas more impressively and to make a particular prezi more engaging to viewers. Prezi runs entirely through web browsers, excluding compatibility issues. Accessing prezi from a mobile device on a device's web browser is very convenient as well as a Prezi Viewer app available for both iOS and Android. Other inviting features are: remote presenting, injecting individuality into a presentation, innovative thinking, real-time collaboration, supporting text, images and video.

Keynote for Mac [21] enjoys wide popularity with Apple users because of Apple device synchronization. A presenter can move from their Mac to iPhone or iPad and vice versa. Keynote offers a great amount of impressive templates, fonts, charts, columns, bars, pies, scatters, bubble charts. A presentation is easy to create – a user

may simply compound available elements and add their own data within. A specifically promoted unique Keynote feature is 'Magic Move' – it animates an object between two slides. Keynote and PowerPoint compatibility is stressed, though it is noted that a presentation of a particular complexity level is going to be easily created by a lay person in Keynote but its Power Point version needs a skillful user. Other advantages of Keynote are: it offers exclusivity (like using .key (presentation files) and .kth (theme files) bundles alongside other file formats), it's free on all iPhone, iPad, and Mac devices, has intuitive design tools, allows adding illustrations and handwritten comments with Apple Pencil on iPads.

Canva [22] is a free presentation tool which slogan is 'Become a visual communicator'. In order to attract users Canva promotes hundreds of professionally designed layouts and over 1 million stock images (either free or premium – priced at $1) to create presentations on any topic. The most appealing feature among active social media users is availability of graphics for any social media platform (pre-sized social media image, sharing a canvas to get comments, sharing a project to allow collaborators to edit). Customers also highly estimate easy editing, sending/sharing canvas and webpage navigation. To simplify access from any devices free iOS and Android apps can be downloaded. It should be noted, that free Canva designs are easily downloaded in a range of file types. Nevertheless, all the premium design elements are to be paid for before downloading.

At this stage the teacher revealed also particular presentation makers' features like pricing connected limitations and available languages. Keynote is available in Russian and Ukrainian and other 31 languages, Canva – in 117 languages, Russian and Ukrainian are on the list. It is unreasonable to order students to use English interface only because of online translator accessibility. Instead, it is sensible to motivate potential speakers to do slide editing intuitively, unless they have learned the key words beforehand. Another way of improving the vocabulary for creating and presenting is to shift students' attention towards Prezi, to stress its visual peculiarity and prospects for creativeness since Prezi is available in 9 languages only; among them neither Russian nor Ukrainian are available.

The main features of three applications for online presentation creating and presenting opted for by the students are given in Table 1.

Table 1. Main features of the online presentation software.

	Ready-made professional quality templates	**Unique features**	**Collaborative editing**
Prezi	free	zooming, object rotating	up to 10 people
Keynote	free	Magic Move, writing with Apple Pencil	up to 100 people signed in to iCloud
Canva	free, premium	–	up to 3000 free team members

After having discussed all the presentation editors, students have chosen by vote one online editor – Prezi, which seemed to them most productive and attractive. Namely with this chosen web browser presentation maker the student group has continued their work. Under the teacher's guidance students have signed up and logged in, created their profiles and have read and accepted the license agreement in English.

In case of split decision on one editor for the collaborative review, the home task for not agreeing to majority choice students can be logging in to another (competitive) online editor and exploring its basic functions as a registered user. The home task for the rest of the group may be composing written instructions on using the basic functionality of the chosen online presentation maker.

The next stage is teaching students embodying their ideas into texts appropriately in order to present them with an online presentation maker (in this case Prezi). The preconditions for successful narrative and visuals combination are:

1. Visual means should be chosen in correspondence with the narrative. Both theme and text style are crucial for creating visual accompaniment to reports. Online editors offer a wide range of bright templates and elements, options and effects. Nevertheless, the task is to present an idea and to achieve communicative goals (to inform, to convince, to engage the viewers) and not to demonstrate all the possible features of a particular presentation maker.

2. A well-thought structure. The text should have clear introduction, body and conclusion. Progressing should be reflected through slides entitled correspondingly.

3. Ideas in every section and successive subsection should be brought out in a presentation through scaling font size, highlighting or underlining.

4. Every unoriginal data or idea (usually cited in a text by placing quotation marks and brackets with reference list number) should be referred to through verbal authors /source mentioning and through corresponding comprehensive slide inscription.

5. Every external link a speaker refers to (a video, background materials or reference tools) should be introduced and the reason of their inserting into the presentation should be explained orally.

6. Every controversial or debatable issue should be presented as a separate slide or object in order to be accessed quickly in the course of post-presentation discussion.

7. It should be stressed that using online editors could influence report timing. Soundly selected options (like animating and zooming) can enhance progressing while viewers look into numerical data, when contrasting and deduction making are intended. On the other hand, excessive text or data amount on a particular slide can cause prolongation in its scrutiny.

8. Even experienced presentation editor users should train and preview their performance several times in order to make sure it is captivating, well balanced, does not shift viewers' focus towards text or visual means, proves speakers' sense of timing.

To sum up all the mentioned above strategies it should be inculcated in potential speakers that using an online presentation maker can be highly productive and can help them to stand out against other speakers whose reports are accompanied by less impressive visuals. However, creating presentation in an online editor takes up much more meticulous preparation, enlarges design timetable and demands thorough training.

As far as a teacher is concerned, after detailed explanation, a well-founded persuasion speech, demonstrating online editor impressiveness by personal example (giving a presentation to students) and assisting inspired beginners in working out a web browser presentation, a teacher can benefit from their efforts: students understand the sustainable development presence necessity and are able to discuss it; they know the principles of speaking and are able to share ideas, to impress and to build consensus verbally in their future engagements; they are able to choose appropriate visual accompaniment to achieve their communicative goals, their presentations look bright and up-to-date. Therefore, multiple presentation assignments within an academic discipline have a distinct advantage when teaching Engineering and Computer Science students creating and giving English presentations. While cooperating with a teacher and creating their own product within the educational approach to training application of online presentation makers students experience the interactive, learner-centered and action-oriented pedagogy technique which is one of the crucial elements of Education for Sustainable Development developed by UNESCO.

5 Conclusions

In conclusion it should be stated that purposeful improvement of communication skills should be an inevitable component of educational activities in English as academic discipline in accordance with the 21st century skills strategy and sustainable development goals. A presentation accompanied with online editors is the most promising task, because students are trained to use an English interface application, to compose a narrative of specific format in order to balance their presentation, inculcated interactive speaking strategies. Students are willing to learn about new means to express themselves and able to soundly opt for the most suitable for them online presentation maker. The role of successful presenting should not be underestimated by students themselves, because it performs the informing, developing, assessing and educating functions and ensures teaching and learning to think and act for themselves according to the Learning Outcomes of Education for Sustainable Development strategy.

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Complementing content of English courses for enhancing communication of IT-professionals for sustainable development

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Abstract. The paper deals with the issue of English language training for IT-specialists at Ukrainian universities. Understanding the importance of studying foreign languages has been confirmed by a number of normative documents. Peculiarities of professional training of IT-specialists at higher education institutions with the focus on foreign language training are considered. Pedagogical conditions for formation of communicative competence of IT-specialists are analysed. The content analysis of existing English language course books and textbooks for IT-specialists has been conducted to find out the content of foreign language training. It is stated that English language teaching aids in information technology, computer engineering, computing and software engineering can be used in the learning process, however, their use requires thorough refinement and modification. The series of guides and manuals for teaching English for professional purposes are presented.

1 Introduction

Education institutions have always been the space for implementation of new ideas, venues of progressive events and places for changes and new discoveries. It comes as no surprise universities around the world have become main promoters of sustainable development ideas and goals. Education for Sustainable Development (ESD) emphasizes the necessity of "equipping students with the knowledge and understanding, skills and attributes needed to work and live in a way that safeguards environmental, social and economic wellbeing, both in the present and for future generations" [1].

Modern realms prove that much more attention is given to environmental and economic spheres of life, while the socio-cultural area remains untouchable [2]. Languages, communication, human interaction are essential parts of human lives, and they cannot be disregarded in this respect. In addition, the question arises of why languages are missing from the Sustainable Development Goals (SDGs), as these are precisely languages that can deliver the SDGs correctly and accessibly. Moreover, "99% of negotiations on the SDGs were done in English, and 100% of negotiation outcomes were written in English" [3].

Nowadays. foreign language training is an integral component of all stages of secondary and higher education, and this process becomes even more significant under the conditions of ESD. The high level of the language proficiency, certainly, fosters career promotion, the increase of the intellectual and cultural levels of specialists, and easy adaptation of them in a foreign language environment. Employer requirements for engineering and technical knowledge, skills and competences are constantly being complicated. This happens due to the accelerated evolution of technical skills, the emergence of new engineering professions and the penetration of technology in all the areas of human lives. This fact also imposes an imprint on the foreign language level requirements. The significance of the sufficient foreign language level for IT-professionals is even more crucial, as they often work in international companies or teams, therefore the foreign language knowledge impacts on the result of their individual or joint work.

The objective of the paper is to carry out the analysis of existing course books and textbooks for IT-specialists in the context of their training at higher education institutions.

2 Peculiarities of training for IT-specialists at higher education institutions

The analysis of scientific publications has shown that peculiarities of professional training of IT-specialists have been studied by O. Dubinina [4], A. Striuk [5], M. Sydorov [6], L. Tereminko [2] et al. Researchers V. Kruhlyk [8], V. Osadchyi [9] have been engaged in the analysis of professional qualities of software engineers. Certain aspects of communicative training of IT-specialists have been investigated by H. Babii [10], Ya. Bulakhova [11], I. Chirva [12], O. Kirilenko [13], V. Strilets [14] and other researchers.

A. Striuk [5] notes that a software engineering specialist must be familiar with computer hardware,

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system infrastructure, methods, tools and technologies for developing software; be able to design, develop and maintain software. The scientist emphasizes that in the field of information technology big and small projects that require skilled management are implemented, and therefore students of the "Software Engineering" speciality learn to solve the problems of justification, planning, ensuring economic efficiency, quality and timely implementation of software projects working in teams. In the context of globalization, the development of software using the Internet is widespread, so students learn the appropriate technologies. The author focuses on soft skills of students majoring in software engineering, but he does not fully take into account the importance of foreign language training for IT-specialists.

L. Tereminko, studying problems of communicative competence improvement for competitive IT-professionals emphasizes that they are largely related to the low adaptability of the education system and, as a result, university graduates to the dynamic changes in the IT-industry. Therefore, one of the requirements for vocational training is the formation of student readiness for professional mobility as an integrative quality of the individual, which is the ability to actualize their potential opportunities for adaptation to rapid changes in the professional sphere, formed on the basis of awareness of the need for the specified quality in their successful professional realization and their high level of the professional competence, their desire to develop professionally and to succeed [7]. The researcher notes that professional disciplines have a great potential for forming readiness for professional mobility, and this process can be successfully supplemented by such disciplines of other cycles as foreign languages, in particular, English for professional purposes, psychology of business communication, and ethics and aesthetics.

An important contribution to the theory of vocational training of future specialists in software engineering has been made by O. Dubinina, who has developed the job description for a specialist in the field of software engineering. She has divided qualities that ensure the success of such a professional into personal qualities, interests, aptitude and abilities. The researcher has identified the professional tasks that such a specialist should solve, according to the types of professional activity. In particular, she identified the following professional tasks in the process of analytical activities of software engineering professionals: collecting and analyzing customer requirements for software; formalization of the subject area of the software project by the results of the terms of reference and rapid examination; assisting the customer in evaluating and selecting software options; participation in preparation of the commercial offer to the customer, preparation of the presentation and approval of the package of contract documents. The tasks of designing activities are the following ones: participation in the design of software components to the extent sufficient to design them within the task; creation of software components (coding, debugging, unit and integration testing); performing measurements and refactoring code according to plan; participation in the integration of software components; development of test environment, creation of test scenarios; development and execution of sketch, technical and working project documentation [4].

The technological activity implies the ability to perform the following professional tasks: development and application of automated design, development, testing and maintenance of software; development and application of methods and tools of management of engineering activities and processes of software life cycle; use of standard control methods, evaluation and quality assurance of software; ensuring compliance of the developed software products and technical documentation with Ukrainian and international standards, specifications, departmental normative documents and standards of the enterprise; participation in the research related to the subject of professional activities in accordance with approved objectives and techniques. Production activities are the following: interaction with customers in the process of implementation of the software project; participation in software development processes; participation in the creation of technical documentation on the results of the works; participation in the preparation of technical documentation and established reporting in the approved forms; planning and organizing your own work; planning and coordination of software setup and maintenance work; drawing up a technical task for software development; organization of work of small teams of program project executors; participation in the feasibility study of program projects; commissioning of the software; preventive and corrective maintenance of the software product during operation; training and consulting of users on work with the software system [4]. However, the scientist has not emphasized that most of these professional tasks will be difficult to accomplish without having the rather developed communicative competence, including the foreign language communicative competence.

M. Sydorov, I. Mendzebrovskyi, and A. Orekhov on the example of the Professional Practice of Software Engineering discipline puts forward the following requirements for the organization of professional training of specialists in software engineering. First, students should be prepared to adapt to specific work that is as close as possible to their real work, and teachers must be practically and professionally trained (in terms of software development). Therefore, it is advisable to conduct training within a software development company; involve professional developers in teaching disciplines; to organize practical classes according to modern requirements. Second, students should integrate their own knowledge and skills and direct the results to software development, and teachers, using appropriate teaching materials, should simplify this integration [6]. In their study, the authors have not focused on communicative training for future software engineering professionals.

This deficiency of research in the national scientific thought has been eliminated by some pedagogical studies. In particular, the researcher O. Kirilenko, on the basis of the analysis of international requirements for software engineering teaching (Curriculum Guidelines

for Undergraduate Degree Programs in Software Engineering ACM / IEEE), notes that the listed abilities include not only highly specialized engineering knowledge, skills and qualities, but and "skills in effective reasoning, ability to work in a multidisciplinary team, understanding of professional and ethical responsibility for making engineering decisions, ability to analyze and criticize decisions, people management skills and understanding of the importance of lifelong learning "[13].

H. Babii considers the proficiency in professional communication to be important for software engineers, because "it is necessary to involve the whole team of specialists for development of modern software, which requires knowledge of teamwork skills, knowledge of psychology fundamentals, group dynamics and communication, which is a guarantee of achievement of professionally significant results" [10]. The researcher identifies two groups of competences that she considers as the basis of the cognitive component of the readiness for professional communication of future software engineers: instrumental and specialized-professional competences. The first group, according to the researcher, includes the ability to write and communicate in the native language (the ability to use the language correctly depending on the scope and purpose of communication, to make business papers); knowledge of another language(s) (practical knowledge of a foreign language in terms of subjects due to professional needs); the use of oral language within the framework of domestic, social and political and professional subjects; the ability to translate general economic texts from a foreign language into a native language); research skills (ability to apply research skills in specialized disciplines); the ability to create technical documentation for a software project. The second group includes the ability to conduct business negotiations with business partners and the ability to reasonably convince colleagues of the correctness of the proposed solution, the ability to convey to others their position [10].

I. Chirva believes that in today's realities there is a growing need for future software engineers to develop the skills and abilities of dialogic speech itself, which is conditioned by economic reforms being carried out in Ukraine at the present stage (contacts of specialists of technical profile with foreign partners when creating joint ventures, work with imported equipment, etc.). The scientist assures that students must be able to communicate effectively in English. According to the requirements of the English for Specific Purposes (ESP) program, a prospective professional should be able to respond to basic ideas and identify relevant important information during detailed discussions, discussions, formal talks, lectures, related conversations with training and profession. The high level of foreign language communicative competence of future software engineers is a guarantee of improvement of their professional level, enrichment of knowledge in a speciality and successful professional activity [12].

According to the Ya. Bulakhova, in their professional activity software engineers "must actively cooperate with foreign partners, representatives of different cultures and levels of professional competence; be aware of the latest scientific and technological developments in their manufacturing field, using foreign sources of information. The success of their professional activity depends on communication skills and knowledge of a foreign language". On this basis, the author insists that for the effective mastery of a foreign language, the following requirements must be taken into account: the orientation of the teaching system to the formation of students' systemic vision of the subjects studied; flexibility and variability of content, taking into account the needs of education and the individual; humanization of technical education; orientation on mastering new information technologies; ensuring the methodological, specialized scientific and professional competence of the specialist. While studying, students should be aware of the substantive and procedural part of their future professional activity [11].

The same opinion is emphasized by V. Strilets, pointing out that modern society needs specialists in programming who have the system thinking, are able to generate ideas, be aware of the responsibility for the consequences of the decisions made, quickly adapt to new conditions, find ways to overcome problem situations; are able to navigate the information space, quickly find and process the necessary information, use electronic communications, a variety of software when solving production tasks. In the professional field, software engineers mainly use foreign language when searching for and processing information from Internet resources, programming, and communicating with foreign partners through electronic communications [14]. Therefore, the process of foreign language training of future specialists in software engineering is important. The author highlights the following communicative skills of future programmers: reading in various modes (search, study, study) computer messages, system help programs, specifications, instructions, articles of electronic professional publications, materials of professional community forums, online workshops; participation in dialogue / discussion-dialogue, communicating both directly and through electronic means; production of a monologue presentation; writing instructions, reports, forum posts. Their formation is proposed to be implemented in the process of the project methodology of teaching English to future programmers using a distance course.

A high level of foreign language communication competence in the professional activity and professional environment is considered to be a necessary component of the characteristic of a modern IT-specialist. According to the research of I. Viakh, an IT specialist is considered competent if he or she successfully completes the following tasks in a foreign language: 1) finds the necessary information in a foreign language text without assistance; 2) understands technical instructions, articles, educational texts in foreign language from popular and promising areas of the IT industry without assistance; 3) uses tools that accelerate and refine the comprehension of a foreign language text (various electronic dictionaries, glossaries); 4) constantly improving foreign language skills; 5) makes a structured

written presentation in a foreign language; 6) conducts competent correspondence in a foreign language with the customer, employer through messenger programs, e-mail; 7) states the facts in a foreign language clearly, clearly orally and in writing; 8) competently and objectively verbally presents in a foreign language himself, his skills, experience, goals, aspirations; 9) draws up an effective competent resume in a foreign language, is able to sell his skills; 10) makes oral presentation in a foreign language; 11) formulates and communicates its ideas, proposes both verbally and in writing in a foreign language; 12) provides technical guidance in a foreign language, both orally and in writing; 13) advises clients and colleagues in a foreign language; 14) explains information to different audiences in a foreign language; 15) clarifies information for itself in a foreign language; 16) effectively agrees with the customer in a foreign language on: a) the subject area; b) product requirements; c) payment; d) terms; e) support; 17) distinguishes the main from the heard broadcast in a foreign language; 18) understands oral language directly, via telephone or messenger programs; 19) understands and takes into account the concept of time in different countries; 20) knows domestic and international business etiquette; 21) possesses socio-cultural knowledge of other countries (holidays, weekends, greetings, taboo topics, etc.) and takes them into account when communicating; 22) is engaged in professional self-education, reading professional literature, blogs, forums in a foreign language; 23) participates in the project, project planning, project management and evaluation of the project using a foreign language [15]. Thus, the researcher concludes that foreign language communication competence is a decisive factor in employment and career development in the IT field.

3 Pedagogical conditions for the formation of communicative competence of IT-specialists

The conditions under which communicative competence of modern professionals is formed have been investigated by O. Kraievska [16], I. Novgorodtseva [17], O. Yefimova [18], Z. Yermakova [19], in particular, communicative competence formation of future IT specialists has been studied by Ya. Bulakhova [11], I. Viakh [15], V. Chirva [12] and others.

O. Yefimova [18] defines the following pedagogical conditions, the observance of which ensures that students achieve a higher level of communication competence formation: 1) development of teacher empathy; 2) development of communication skills; 3) individualization of training (introduction of academic counseling (tutoring)) [11].

O. Kraievska [16] among the pedagogical conditions for the development of communicative competence of future agrarian managers places the need for the gradual formation of motivation for the communicative activity in the process of professional training of future agrarian managers. The other pedagogical condition is the development of the content of communicative training of future agrarian managers on the basis of systematic and integrative approaches. The implementation of these conditions is the basis for applying the methodology of complex formation of structural components of communicative competence using information and communication technology, which is advanced by the researcher as the third pedagogical condition.

I. Novgorodtseva determines that the formation of the professional communicative competence of future engineers at higher education institutions will be effective under the following organizational and pedagogical conditions: 1) orientation of professional training to the professional-communication competence of future engineers; 2) development of the author's training courses aimed at the formation of the professional and communicative competence; 3) development and use of the algorithm of formation of the professional communicative competence of future engineers, containing three interrelated stages: preparatory (knowledge), basic (activity), and final (reflective) ones; 4) use of pedagogical technologies, a complex of didactic means in the process of professional training of future engineers; 5) development of a system of criteria for assessing the levels of the professional communicative competence of a fut7re engineer [13].

I. Viakh has identified the following conditions for the formation of foreign-language communicative competence of future specialists in the field of information technology: systematic learning the industry-specific content in a foreign language, modeling the professional activities of future specialists in the field of information technology by means of a foreign language, implementation of the principles of mixed learning materials in teaching materials [15]. The researcher has paid particular attention to the use of information and communication technologies in the process of forming foreign communication skills of future specialists in the field of information technologies, namely applying instant messaging programs Skype, Google Talk, ICQ, QIP, Miranda, professional electronic journals (Tech Crunch, Computer, EEEM), blogs (A + Computer Science Blog, Pastacode computer science blog, etc.) and country sites.

Exploring the methodological approaches to teaching English dialogues of future software engineers, I. Chirva [12] believes that creating a favorable environment with the use of level differentiation is important for mastering each student according to the level of their academic achievements and abilities. In her opinion, it is advisable to introduce a computer program for the organization of differentiated teaching of English dialogues of future software engineers in a technical institution of higher education, which is justified by the need to improve the quality of foreign language training of future software engineers at all levels; the need to obtain the desired result is to increase students' skills and competences. Instead, the researcher Ya. Bulakhova identifies meaningful and procedural pedagogical conditions for teaching software engineers, which take into account the connection between social contract for engineering training, contradictions at national higher education

institutions and the specifics of teaching a foreign language at a university [11].

Based on the research of Z. Yermakova, we follow this understanding of the pedagogical condition: a circumstance on which the performance of professional activity depends and in which different results are possible [19].

The analysis of modern requirements for the organization of professional training of software engineers in Ukraine and abroad, the generalization of the experience of forming communicative competence of IT-specialists allow us to distinguish the following organizational and pedagogical conditions for the formation of communicative competence of software engineering specialists at institutions of higher education [20]:

1. Complementation of the content of curricula and educational-methodological complexes of foreign language disciplines with exercises, activities, texts and patterns of effective professional communication.
2. Application of interactive forms of training of selected professional disciplines, taking into account the specifics of professional activities of software engineers in the implementation of dominant methods (project method, method of teaching in collaboration (small groups), "brainstorming", case method).
3. Use of synchronous and asynchronous communication tools, special Internet resources, social online networks and virtual communities in the teaching of foreign language and vocational disciplines in foreign language in classroom and extra-curricular work.

The efficiency of the process of forming techniques and methods of interpersonal interaction, which form the basis of professional communication of software engineers is ensured by involving students in communication activities, which maximally simulates the process of professional interaction and creates the conditions for professionally and personally-oriented professionals.

4 Content analysis of course books and textbooks for teaching English for IT-specialists

In order to complement the content of curricula and educational and methodological complexes of foreign language disciplines with exercises, activities, texts and patterns of effective professional communication we have analyzed the contents of course books and textbooks for teaching English at higher education institutions, and in particular for specialists in computer science, information technology, Internet technology and software engineering. The similar research has been carried out by Japanese educators J. Jodoin and J. Singer to analyze the contents of English textbooks to find out whether this material is used effectively to train university students in terms of SDG [21].

In our research the following aspects have been emphasized: the professional orientation of the content, the presence of exercises, tasks, job-related situations and activities for the development of all four language skills; the availability of additional materials, applications and resources for self-study.

The English Language Guide for PC Users and Programmers [22] provides educational materials for teaching English to technical students and students studying the English language, computer science and advanced computer technology. Each of the 25 lessons has two sections: Grammar and Vocabulary and Reading. The first section contains materials for learning English grammar in the traditional format. The second section contains a list of words for one or more texts and general exercises for vocabulary training on the main topics of computer science and programming. The benefits of the manual are its original structure and the use of basic special vocabulary, but the disadvantages are the moral obsolescence of the texts, the absence of listening activities and the lack of focus on developing communication skills, including the lack of dialogue practicing and job-related phrases.

The English for Internet Technology Professionals guide [23] is aimed at developing and developing language skills and skills in the language use in the field of professional communication. It contains authentic texts, tasks for listening and speaking, and vocabulary on seven topics: history of the Internet, Internet privacy, Internet services, online payment systems, E-mail service, personal web page, Internet security. The benefits of this guide include the availability of exercises and tasks for practicing communication skills (discussions, dialogues, reflections), but the vocabulary is limited to only one field – Internet technologies, which will not obviously be enough for IT-specialists to communicate.

Oxford English for Information Technology course book is intended for students majoring in information technology and computer engineering, for professionals already working in the field and who wish to improve and expand their English language skills in the context of information and communication technologies. Compared to the first edition of 2002 [24], the 2006 edition [25] takes into account the latest developments in this fast-growing sector, as reflected in the content update. New materials reflect changes in areas such as specifications, new technologies and practices. The student's book consists of 25 lessons covering a wide range of IT topics. The materials of the course book include authentic texts and visuals taken from textbooks, newspapers, popular computer magazines, online newsgroups, webpages, manuals and advertisements. Each lesson contains tasks for language skills development, and every fifth lesson focuses on developing listening skills through authentic interviews with IT professionals. For students who already have rather good knowledge of English vocabulary in IT, there are additional special reading texts. The teacher's guide includes a theoretical introduction to the topic of each lesson for non-IT teachers to better achieve the learning goals. However, the manual does not sufficiently focus on software development issues, communication with the team members and customers, which is an important topic for training software engineering professionals.

The organization and drawbacks of the Professional English in Use: ICT manual [26] and English for Information Technology. Vocational English [27] are similar. The first covers a wide range of topics in information technology, including word processing, financial software and databases, multimedia applications, e-mail, web design and Internet security. Easy to use and clearly written, designed as a reference and practical manual for independent work, it can also be used as a supplement to classroom work only to improve the vocabulary of future software engineering professionals. The second book is intended for IT-students and company employees and includes topics in current IT development, it has clear learning goals, online teacher support, CD-ROMs with audio files and interactive glossaries in US English and British English for students.

The English for Computer Science Students textbook [28] is offered for the analytical or home reading of vocationally-oriented texts, vocabulary boosting, English-speaking skills in oral and written forms. It consists of 9 lessons, each of which in addition to the industry-specific texts contains a number of interesting exercises aimed at mastering scientific and technical vocabulary, namely terms, abbreviations, acronyms, etc. The guide is aimed at students, graduate students and anyone with a basic knowledge of English and interested in current issues related to the emergence, development and future of computers in the global computerization of society.

Among the analyzed publications the Express Publishing editions of Career Paths series are of special interest. The series is intended for professionals who want to improve their English language skills in the work environment. They include a special vocabulary and texts, step-by-step tutorials that immerse learners into four major language aspects: reading, listening, speaking and writing. The course book contains three books in three difficulty levels (A1, A2 and B1) and offers over 400 lexical terms and phrases. Each lesson includes a test to check reading comprehension, vocabulary and listening skills, and help students develop their writing and oral communication skills. The Career Paths: Information Technology Guide [29] covers topics related to computer design: components, hardware, software, Internet security, web design, and the future of the IT industry. The Career Paths: Computing Guide [30] is intended for professionals who want to improve their English communication skills in the computer industry. It includes topics related to computer hardware, general applications, operating systems, online communications, and cloud computing.

The Career Paths: Software Engineering Guide [31] discusses topics in software development, software testing, user interface, modeling, and career options in software engineering. An important structural element of this publication is dialogues specific to the profession and the numerous job-related texts in the field of software engineering. Therefore, this guide combines specialized vocabulary and professional context to form necessary communication skills for a career. The textbook contains three books of different levels: Elementary (Book 1), Pre-intermediate (Book 2), and Intermediate (Book 3). The books contain 15 lessons of different topics, each topic focuses on a specific reading context and serves to form a certain communicative skill. For example, the second lesson on Types of Computers contains the text for reading in the form of a magazine article, which involves new vocabulary acquisition (computer, computing cluster, desktop, embedded computer, laptop, notebook, PC, server, tablet, workstation) and aimed at forming ability to make plans. However, despite the elaborate structure, professionally oriented exercises, texts and dialogues, the disadvantage of the course book is that there is no consistency between the topic of the lesson, the vocabulary words to learn and the skills formed during the lesson.

The content analysis of course books and textbooks for English learning at higher education institutions, in particular, for professionals in the field of information technology and software engineering, has shown the abstract nature of the used case studies and low applied importance of the chosen topics of educational interaction. Therefore, as a result of the analysis of English language teaching aids in information technology, computer engineering, computing and software engineering, we can conclude that some of them can be used in the learning process, however, their use requires thorough refinement and modification.

In order to improve the content of English language learning to form communicative competence of software engineering specialists at higher education institutions, taking into account all the advantages and disadvantages of existing teaching aids we have developed and implemented the following items:

1. The Improve Your Listening and Speaking for Future Software Engineering Professionals guide.
2. The Business English Essentials for Software Engineers manual.
3. The Dictionary of Acronyms and Abbreviations for Information Technology and Software Engineering Specialists.
4. Methodological Recommendations for the Formation of Communicative Competence of Future Specialists in Software Engineering.
5. Distant courses for studying English, English for Special Purposes and Business English.

The Improve Your Listening and Speaking Guide is intended for students of IT-specialities. It is aimed at teaching listening for better comprehending foreign language information, understanding general information, finding out the main ideas, extracting certain details or facts, and predicting key information before listening. The guide includes 24 sections covering a wide range of information technology issues: computer history, modern computers and their use in society, the Internet, global communications, wireless technology, computer games, digital libraries, software interfaces, graphical interface, software and others. The texts are selected from original modern sources, taking into account the latest trends in information technology and interests of modern students. The guide contains numerous diagrams, charts and illustrations that facilitate

the perception of information and tasks. The manual includes audio files with scripts.

Each section contains a list of specific terms, listening tasks, and professional texts. The activities cover a number of questions that require not only specialized but also personal general knowledge regarding IT problems. Listening tasks vary in their form: answering questions, writing down terms, selecting facts in a report, filling in a chart or table using facts from a report, filling gaps, etc. After-listening activities typically involve discussion questions that develop speaking skills in the professional software engineering environment.

The Business English Essentials for Software Engineers guide is intended for senior students of IT-specialities. It should be noted that the manual is designed to deepen the students' language skills in reading and speaking, improve their writing skills, as well as develop their ability to process original and prepare their own documents in English. The guide consists of 10 units covering the main types of business oral and written communication in software engineering. At the beginning of each block the list of active vocabulary is given. Post-text exercises are aimed at productive and reproductive activities. To simplify the processing of authentic and didactic materials, the guide contains a large number of samples of English-language documents in software engineering and information technology in general, intended for both classroom use and self-study. The information is retrieved and adapted from modern online materials and resources.

The Glossary of Software Engineering Acronyms and Abbreviations contains 12,000 terms and is intended for students who study IT and it is also useful for teachers of professional disciplines who train future IT-specialists.

Methodological Recommendations for the Formation of Communicative Competence of Future Specialists in Software Engineering provide student advice for oral and written communication in the work environment and in the software development process. The manual is intended for students who are interested in software engineering as a field of information technology, which deals with the application of a systematic approach to the development, use and maintenance of software, and the study of these approaches, i.e. the application of engineering principles to software. The manual also features an English-Ukrainian phrasebook for software engineering professionals.

The guide contains 12 topics that address situations, problems, and tasks that arise during professional activities in software development. Tips on writing business letters and cover letters, talking on the phone, writing a resume, looking for a job, holding a teleconference, presentation or meeting using professional English vocabulary and word-specific words are provided. Useful phrases for communicating with clients and colleagues are also given. Each topic presents language patterns of business professional communication in the field of software engineering.

The materials of the manual are presented in the form of communication patterns, which are easily perceived by students in the learning process, because they have a standard structure and are used in typical professional situations. Having studied the language patterns, presented in both English and Ukrainian, grouped in the manual according to professional situations, students will quickly be able to recall them in real-world professional activities and demonstrate the high level of communicative competence.

Combining disparate means of communication and purposeful influence on the formation of communicative competence is enabled by distance learning technologies. In order to support student self-study, distance learning courses for studying English, English for Special Purposes and Business English on the Moodle platform have been developed. The courses contain basic theoretical materials as well as additional materials: theoretical explanation of grammatical phenomena in the native language, audio and video materials with relevant tasks for understanding comprehension, conversational topics with tasks and comprehension check, texts for extra-curricular reading with tasks. The topics of the course are in strict accordance with the curriculum of the discipline. The students' progress in the course has been checked after each topic.

In order to facilitate communication in a foreign language, a chat has been created in the distant courses to ask questions, leave comments, answer questions, and share useful information.

5 Conclusions

Our research has made it possible to identify the progressive ideas of modern pedagogical science and to develop recommendations for improving the formation of communicative competence of IT-specialists at higher education institutions. Vocational training of IT-specialists in the 21st century should involve significant intensification of language training, whereby synergies should be achieved through a set of training measures of active professional and linguistic training within separate practical courses; foreign language training should have the real-life flexible and variable context, taking into account the field of knowledge, its current state and sustainable development strategies and ideas. In the vocational training of IT-professionals coherent problem modules with elements of private, business, academic professional and scientific communication in both oral and written formats should be implemented. It is necessary to emphasize that foreign language teachers need to modify the content, forms and methods of teaching foreign languages according to ESD to meet the requirements of professional communities in order to ensure the proper level of English command.

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Development of future foreign language teachers' information literacy and digital skills in Ukrainian context

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Abstract. The aims of this paper are to share the results of the action research of the future foreign language teachers' information literacy and digital skills development and to demonstrate the opportunities for their development while pre-service teacher training process in the course of Methodology of foreign language teaching and practical course of foreign language. The article discusses the skills of information and communication technologies use in learning and teaching as an important component of future teachers' training and a contribution to the sustainable development of the country. The projects which influenced the action research elaborating are described. A short overview of relevant experience within the studied issue is presented. The procedure of action research is described, the examples from author-tailored course are given.

1 Introduction

Modern Ukrainian society moves ahead rapidly and requires immediate actions from the system of higher education as it is responsible for the professional training of highly-qualified specialists in various branches. However, the initial responsibility is surely on secondary education which prepares the basis for the further professional journey. Thus, a teacher is considered to be a rather important person in the development of the society.

While the students obtain their higher education, the reality changes and they take risk to acquire the out-of-date model of professional competence. It is a challenge to find the way out of this situation. Future teachers can and should be taught to develop their own professional thinking, awareness and skills.

In the Decree of the President of Ukraine "On the Aims of Sustainable Development of Ukraine within the Period till 2030", it is pointed that to promote the national interests of our country, the diverse and equitable quality education and opportunities for life-long learning should be provided for all Ukrainian people [1].

Information literacy and digital safety are among the most important 21st century skills without which the modern teacher will not be able to provide effective teaching and cater for students' learning under the conditions of continuing innovation and modernisation of education irrespectively of its level (pre-school, primary, secondary, high school, vocational, pre-higher and higher education) or type (formal, informal).

It is stated in the United Nations Agenda for Sustainable Development that "the spread of information and communications technology and global interconnectedness has great potential to accelerate human progress, to bridge the digital divide and to develop knowledge societies" [2]. In section b of goal 4 prescribing to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all, it is emphasised that the actions will be aimed at substantial expanding globally "the number of scholarships available to developing countries, …for enrolment in higher education, including vocational training and information and communications technology, technical, engineering and scientific programmes, in developed countries and other developing countries" [2]. The necessity of enhancing the use of information and communications technology is focused in the document.

The role of education in sustainable development as the key issue is emphasised in United Nations documents and is presented in reflections on "A Decade of Progress on Education for Sustainable Development": "Students should be supported in acquiring (key) competencies, which help lead to a sustainable, future-oriented society. These include skills for creative and critical thinking, oral and written communication, collaboration and cooperation, conflict management, decision-making, problem solving and planning, using Information and Computer Technology (ICT) appropriately, and practical citizenship" [3]. The purpose of this reflective paper is to take into considerations the achievements and pressing challenges of the previous work and research.

The aims of this paper are to reveal the importance of the future foreign language teachers' information literacy and digital skills and to demonstrate the opportunities for their development while pre-service teacher training

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process.

2 Methods

The methodology of our research is presented with step-by-step procedure of action research.

The action research contained several stages according to Dai-Ling Chen procedure [4]:

- identifying problem of meaning (starting point, kick off, notice, find interesting area, etc.);
- developing questions and examine assumptions (reflect and formulate questions);
- planning (choosing enquiry strategies, ways of gathering data, planning interventions);
- taking action (intervening);
- gathering data (wider evidence);
- analysing data (reflecting on wider evidence, qualitative analyses);
- interpreting data (assessing impact on teaching and learning);
- reporting (formulating recommendations);
- taking action (wider scale intervention).

The issues of future foreign language teachers' pre-service training are rather well-studied, though there still are the aspects which have not been paid enough attention. Such an issue is the one associated with skills of handling with information and communication technologies. So, we have studied Ukrainian and foreign experience of the future foreign language teachers' information literacy and digital safety skills.

The next stage of our research was the study which helped us to collect the data about university students' and school teachers' confidence in using information and communication technologies in the classroom.

This study confirmed that it is important to answer the research question: What are the most effective ways to train information-literate and digital-safety aware teacher of foreign language?

While planning the future foreign language teachers' information literacy and digital skills development we took into consideration the results of the survey, trying to cater for all key competences necessary in teaching and organising students' learning.

Taking action, i.e. implementing the tailor-made course "Information and Communication Technologies in Learning and Teaching", which was a separate unit within the course "Methodology of English Language Teaching", was realised simultaneously with finding the evidence of the effectiveness of the suggested content, modes of interaction, motivation and outcomes. To prove that the designed course could really enhance the technologies impact in the classroom we analysed and interpreted the data gained in the process of its implementing.

3 Results and discussions

The need for changes in the system of Ukrainian higher education launched the projects aimed at its modernisation and quality improvement. As Ukraine tries to be in line with European and world standards, international organisations help it to reform all levels of educational system. Recently the reform of pre-school education has just began, the UK Government and British Good Governance Fund support it; New Ukrainian School Concept is based on "Recommendation of the European Parliament and of the Council of 18 December 2006 on Key Competences for Lifelong Learning" (2006/962/EU); Ministry of Foreign Affairs of Finland supports this reform financially; The Lego Foundation contributes to the development of Ukrainian primary school.

As for higher education it is actively supported with the British Council and the British Embassy, America House, IREX and the US Embassy, Goethe-Institute and the Germany Embassy. For the last five years the most crucial in the sphere of teacher training were two projects implemented by British Council and Goethe-Institute.

Goethe-Institute project "Deutsch Lehren Lernen" [5] presents a series of continuing programme of learning based on innovative didactic approach of action research and corresponds to the world quality standards of teacher training. The project system comprises the integration of methodology of language teaching and foreign language learning as two inseparable components of a future teacher's professional competence.

"Deutsch Lehren Lernen" suggests the tasks on systematic observation and reflection on pedagogical activity by means of German language video-lessons from three continents. As the follow-up activities, the students can participate in one-week on-line course moderated by mentors. On accomplishing the course the students are to do the planning and elaborate their own action research project.

The project activity is based on blended learning and combines traditional language learning with digital learning, i.e. doing on-line tasks, new words and patterns revision and use, virtual collaboration with group-mates, virtual class learning, Adobe Connect webinars for both students and teachers with the system of completed tasks monitoring.

There are such effective learning tools as Page Player-App, E-book, introductory on-line test (Einstufungstest online), media-pack, help-test (Testhelf), application for the work with vocabulary (Vokabeltrainer-App), supplementary on-line materials, bilingual glossary. The advantage of the project course is obvious as it promotes and motivates students' learning and helps teachers to deliver their teaching taking into consideration all challenges of modern education and information and communication technologies development.

The project "New Generation School Teacher" [6] was initiated by British Council Ukraine and the Ministry of Education and Science of Ukraine in 2013. It aimed at introducing change to the initial teacher education system in Ukraine. The project resulted with the PRESETT curriculum in Methodology and the network of Ukrainian universities implementing it and proving its effectiveness. The project outcomes were presented with such learning ones as:

- Student-teachers' and newly-qualified teachers' English proficiency is improved.
- Their classroom skills and confidence are enhanced.
- Their digital and social media skills are developed.
- On the level of action outcomes the newly-qualified teachers:
  - teach more effectively and confidently;
  - engage with colleagues;
  - join networks and meet colleagues overseas;
  - can integrate ICT in/outside the classroom;
  - are committed to CPD.

As it can be seen the ICT skills were paid special attention and there was designed a separate unit of the new Methodology course "ICT in Learning and Teaching". Its objectives are to form the students' awareness of the advantages and disadvantages of doing activities on a computer and other electronic devices as opposed to similar paper-based activities; the criteria for evaluating and selecting online resources for language teaching purposes; and to develop their skills to use different software (e.g. MSWord, PowerPoint) for language learning and teaching purposes; make use of social networking sites, blogs, wikis, etc. in language teaching; evaluate the potential of online audio and video for language teaching purposes; assess possible risks of using the Internet with young learners and develop a set of rules for cyber safety; explore current trends in mobile learning and be able to use mobile phones for teaching and learning reference.

The whole project represents the large-scale research which comprised 8 university at its beginning, and 13 universities and colleges within the period of its piloting. Our small-scale research was based in its results but was elaborated on the content prepared and piloted in Bogdan Khmelnitsky Melitopol State pedagogical university only.

Besides of "New Generation School Teacher" project results we used the experience of our participation in the joint project of International Research and Exchanges Board, Academy of Ukrainian Press and Ministry of Education and Science of Ukraine "Learn to Discern: Info-Media Literacy" as its realisation is concerned around integrating info-media focused modules or courses into pre-service teacher training syllabus. In spite of the fact that the project is mostly oriented at the training of teachers of Ukrainian Language and Literature, History and Arts, we have implemented its element in our courses for future teachers of foreign languages.

The amended and modernised curricula of Methodology of Foreign Language Teaching and The First Foreign Language develop teacher profile specialty-based competences as well as critical thinking skills, implement interactive methods of learning and teaching, dialogue modes of interaction, and the ample use of online tools.

While identifying the issue for doing our action research we studied the experience presented in scientific-methodological resources and found out the challenges and opportunities for our learning and teaching context.

The role of information and communication technologies in higher education has been being studied since the very beginning of their appearance and application in this branch. The issue has its diachronic and space aspects, i.e. in different periods we observe the studies of various technologies and the context of national systems of education, types of educational institutions, technical and financial capability, and other numerous factors have an impact on the ICT use and their role.

The experience of developing countries demonstrates that the role of ICT for sustainable education has always been considered the potential positively transform the higher education though the accessibility of ICT facilities is still low. Such conclusions were made in 2011 by S. A. Bello and S. Johnson from University of Lagos in Nigeria. Their data were collected from 800 lecturers selected from 16 higher education institutions in the country [7]. The researchers admitted that the problem was associated not only with the availability itself, but with the digital and information illiteracy of teachers.

A year later a similar research was presented by Ajit Mondal and Jayanta Mete, scientists from India, who pointed that "the introduction of ICTs in the higher education has profound implications for the whole education process especially in dealing with key issues of access, equity, management, efficiency, pedagogy and quality" [8]. They assessed the importance of solving the problem as the one meeting the stakeholders' needs and expectations. Thus, these scientists ascertained such benefits of ICT in education to the main stakeholders: "increased access, flexibility of content and delivery, combination of work and education, learner-centred approach, higher-quality of education and new-ways of interaction" for students; "high quality, cost effective professional development in the workplace, upgrading of employee skills, increased productivity, developing of a new learning culture, sharing of costs and of training time with the employees, increased portability of training" for employers" "increase the capacity and cost effectiveness of education and training systems, to reach target groups with limited access to conventional education and training, to support and enhance the quality and relevance of existing educational structures, to ensure the connection of educational institutions and curricula to the emerging networks and information resources, to promote innovation and opportunities for lifelong learning" for governments [8].

It is obviously that the ICT use in higher education provides for both personal professional development and the world's information-digital-literate society. Modern education should be available for all people always and everywhere. That is why "life-long learning has become the driving force to sustain in the contemporary competitive environment. Therefore to strengthen and / or advance this knowledge-driven growth, new technologies, skills and capabilities are needed" [8].

The other scientists' action research reports supplied us with additional evidence that we are on the right way. Such research was elaborated by Beata Lewis Sevcikova

who integrated information technologies into TEFL training. When she summarised the action research activity she noticed that the students "believed that technology is essential for the future; it enhances learning and teaching, supports collaboration and motivation. They also pointed out some limitations such as IT literacy, the time-consuming nature of technology, and the lack of access to free internet learning/teaching resources" [9].

We used the colleagues' experience as the problems of ICT use in higher education context proved to be similar with many educational institutions from different countries.

The overview of the issue helped with the starting point of our research and finding the relevant area. Still we had to specify the narrow aspects for elaborating and implementing. This was a cause for doing the survey. Our respondents were university students and school teachers. The questions asked were about their attitude to the use of ICT in class, their confidence in this practice, and their skills in handling with cyber well-being, websites and learning platforms choice, online resources use, social networking, blogs, wikis application, flipped teaching, proper use of various devices such as mobile phones, tablets, laptops, interactive whiteboards. There were 200 students and 30 teachers who took part in the survey.

The so-called "digital divide" revealed itself in the process of survey as only two of teachers (6,7 %) answered that they are completely confident as for ICT use in classroom. Completely confident students were 49 %. Though, the questions about cyber well-being, websites and learning platforms choice, blogs and wikis application, understanding of flipped teaching demonstrated that there were some gaps in their information literacy and digital safety skills.

For teachers who took part in our survey we prepared a series of workshops to help them in ICT application in foreign language classrooms.

For students, on the basis of our baseline study we elaborated the unit "Information and Communication Technology (ICT) in Learning and Teaching English" [10] which was based on blended learning and included the following items:

- Modern learning technologies and their relevance for the educational process.
- Cyber well-being: keeping children safe on the Internet.
- Selecting and evaluating websites for teaching and learning purposes.
- The use of learning platforms (e.g. Moodle) for teaching purposes.
- Using online audio and video resources for language learning and teaching purposes.
- Exploration of opportunities offered by social networking sites, blogs, wikis to language learning and teaching.
- The notion of a 'flipped' classroom and its benefits; traditional vs. flipped teaching.
- The main uses of IWBs (interactive whiteboards). and their benefits as opposed to traditional whiteboards.
- Exploration of opportunities offered by mobile devices (e.g. smartphone) in language learning.
- The use of different software and online tools for teaching and learning purposes.
- Power Point making rules.
- Effective ways of information search, finding the primary sources. Accumulating and generalising the information.
- The notions of copyright and plagiarism. Following the copyright. How to avoid plagiarism.
- Teacher's skills in photo, logo, symbols, posters, emoticons, memes, infographics use.

There were no traditional lectures within delivering this unit. The main modes of interaction were presented with games, jigsaw learning, buzz groups, socratic technique, role play, workshop, simulation, cross-over groups, guided reading, lecturette, brainstorming, speaking corners and others. Of all methodology units this one was of the greatest interest for students and positively influenced their motivation to learning. It was confirmed at each session which ended with taking students' feedback.

Each session began with studying the experience on the topic of it. Starting where the students are helped us to choose between possible variables and contributed to making the unit content and methodology of its deliverance more flexible.

Here there are some examples of organising the learning within the unit. In the session devoted to cyber-well-being, after getting acquainted with its principles, watching several videos and brainstorming all ideas about safe use of the Internet, the students make a list of rules for communicating in the world web. They work in groups and find the examples to each rule from the Internet. Each group creates a document on a Google Drive and then works with all lists created by other groups. They add other suggestions or comment on other groups' products. After discussing the rules of netiquette, one student takes a responsibility to make an accumulated netiquette code and shares it with all students.

One more example of work in teams is presented with evaluating the sites. Before doing this evaluation, the students learn the following criteria essence:

1. Audience
2. Credibility
3. Accuracy
4. Objectivity
5. Coverage
6. Currency
7. Aesthetic or visual appeal
8. Navigation
9. Accessibility

After that their teams work with different educational websites and evaluate the possibilities for their use in the narrow context, i.e. they are informed on the age of learners and their level of English.

When one team presents their findings the representatives of other ones ask questions and give comments. The activity is summarised with formulating tips for the work with websites.

The work with online courses was a little more time-consuming for students as they had to begin some courses (according to their learning interests) on various learning platforms such as futurelearn.com or openlearning.com. After diving into their courses and getting access to all platform tools, students analysed the content management, curriculum mapping and planning, ways of communication and management of the platform. On the stage of discussing the platforms the students are asked to reflect on their possible moderating such courses, strengths and weaknesses of them.

The use of social networks in learning and teaching arouse the most interest of students. This topic was studied with simultaneous revision of keeping children safe on the Internet. The students suggested the ways of possible algorithms of social media use for educational purposes. This way of ICT use was studied in micro-teaching as students prepared 1-2 activities for their group-mates playing the roles of school students. Through the prepared activities a student-teacher taught English or German to his/her school students. After each microteaching there was a feedback session aimed at finding positive features and methodological mistakes so that avoid them in real classroom.

Especially valuable for students was the work with wikis and blogs as they promote online writing which is rather important for teachers-philologists. In this case we asked students to create their own blogs. They worked in small groups and had one task per a group. To make use of the task they created the blogs of newly-qualified teachers so that they could use them while having their school experience (practice).

All above-mentioned examples were used in methodology class, though sometimes we applied activities of the same typology in our language classes. We give just one example of a task in the class where German is taught as the second foreign language.

So, the students got a set of QR-codes (Fig. 1) with the help of which they had to find the endings of the statements beginnings of which were given. Then they had to match parts of statements according to the logic approach:

1. ein Buch
2. Insektenspray
3. Sonnencreme
4. eine Taschenlampe
5. Aspirintabletten
6. ein Handy
7. einen Laptop
8. eine Digitalkamera
9. viel Geld
10. eine Kopie vom Reisepass
11. den Führerschein
12. Ohropax

Sometimes students matched the equal numbers of parts, but from time to time there were excessive parts which were not necessary.

In practical language classes especially often were used mobile phones applications as they helped to work with vocabulary and grammar (visualising, training, revision, test control), listening. Writing skills were monitored on the level of messaging. Still for larger pieces of writing we used standard e-mail writing which helped students to learn to write various types of letters. Before writing such letters, they searched the information necessary for that very kind of a letter.

Fig. 1. QR-codes puzzle.

While gathering data on our action research we looked for wider evidence of the unit effectiveness. That is why the same survey was conducted once more. It confirmed that most of students (87 %) began to feel more confident as for ICT use in class. Besides, they were acquainted with a wide range of software, online tools, applications and other methodologically valuable ICT items.

The ICT use in learning and teaching unit was a very dynamic and useful for future teachers. Its importance and relevance were confirmed by students and teachers. It is the call of the time to make the classroom blended and to transfer a part of learning to virtual reality which so important for “digital native” school students. Besides, modern university students are ready to implement the ICT innovations.

The students had a good opportunity to train in using ICT in hands-on activities when they had their school experience (practice). So, their reflective journals they wrote while practice contained the same feedback as in the end of each methodology session: the ICT is a powerful methodological tool and the factor which favours learning and teaching stay effective.

Still the application of ICT in both teacher training and those teachers’ future professional activity can be considered unlimited as the technology is rapidly developing and changing the world around us as well as the educational opportunities. Virtual reality contains the enormous potential for improving the quality of learning and teaching foreign languages. This issue have been studied by S. V. Symonenko, N. Zaitseva, V. Osadchyi, K. Osadcha and E. Shmeltser who emphasized that “the practice of immersion into virtual environment in foreign language learning will enable students to feel themselves an integral part of the professionally oriented situation which is designed specifically to prepare the course participants for communication within” [11]. This team of researchers point that virtual reality tasks help students to get used to “psychological challenges and apply existing speaking skills in a foreign language”, “encourage spontaneity” and increases students’ motivation to “achieve better results in a training course”

[11]. Virtual reality is especially valuable for teaching languages in the conditions of natural language speech environment. Besides of demonstrating "situational models of possible daily life circumstances for foreign language communication" [11], virtual reality-based tasks surely promote the development of future teachers' information literacy and digital skills.

4 Conclusions

The results of our action research helped us to prove the importance of the future foreign language teachers' information literacy and digital safety skills development to our students. The prepared materials, chosen ways of teaching, possibility to apply all they got to know demonstrated to future teachers the opportunities for their development while pre-service teacher training process.

The elaborated unit implementing contributed to the development of future teachers' awareness of the advantages and disadvantages of ICT use in the classroom, the criteria for evaluating and selecting online resources and ICT software and applications for language teaching purposes, skills of using various software, social networking sites, blogs, wikis, online tools in language teaching, evaluating the potential of online audio, video and other visuals, assessing possible risks of using the Internet with learners and creating conditions for cyber safety, using various electronic devices justified for achieving educational aims.

Their Methodology and language classes supplied future teachers with the set of professionally valuable awareness and skills which will encourage them to follow-up their journey from newly-qualified teacher to an experienced one who will be information literate and ready to create digitally-safe learning environment. This is one of the conditions for sustainable development of our country.

There are still a lot of issues waiting for further study and finding solutions. For future teachers of foreign languages it would be a great opportunity to learn handling with the virtual reality with specific purposes in their professional area. Ability of producing digital content is one more urgent need for teachers of any subject. It is important for all modern teachers to become competent in information and communication technologies use as they are to accelerate human progress and work for its sustainable future by means of ensuring inclusive and equitable quality education for the youth.

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Analysis of the current state of distance learning in the vocational education and training institutions

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Abstract. The article presents the clarified concepts' system in the context of the stated research theme, the current state of skilled workers' and junior specialists' distance learning in the Ukrainian vocational education and training institutions. The received data shows: education institutions' regional affiliation and profiles; education institutions' teaching staff experience in using distance learning technologies in teaching; their assessment of prospects of distance learning implementation in the Ukrainian VET system; teaching staff willingness to improve their distance learning technology mastering. The empirical data were obtained, analysed and systemized by conducting the e-survey using Google Forms web-service with restricted access to the form. The results of the SWOT analysis are presented; distance vocational learning implementation strengths, problems, opportunities and threats are summarized. The levels of teachers' readiness to implement distance vocational learning are revealed by diagnosis results. The proposals concerning the constructive solution of distance learning implementation in the skilled workers' and junior specialists' vocational education and training system are formulated and presented.

1 Introduction

The advantages of distance education in recent decades have been demonstrated by the developed countries' leading universities' practical experience. Distance vocational learning for skilled workers' training only starts to be used in the Ukrainian vocational education and training system (VET). VET teachers' and various enterprises, institutions and organizations HR managers' interest to distance learning significantly increased due to: first, the general trend to create a new mechanism of the direct use of information and knowledge in the production and service spheres, i.e. focusing on the processes of continuing education that characterizes the knowledge society [1]; second, the necessity to meet the personal needs in further new knowledge obtained not only by schools' graduates, but also by adults; third, the complex social and cultural and economic situation in the country due to the large number of displaced persons, their need to get new professions, qualifications or to improve them (Law of Ukraine, 2014) [2]; fourth, the construction of a distance learning system enables integration into the world sustainable education area, thus, greatly expands the potential sphere of domestic information and education environment for sustainable education process participants by using the information technologies (IT) modern methods and tools.

At the same time, the problem of future skilled workers' and junior specialists' distance learning technology implementation in Ukraine remains poorly researched, which makes it impossible to assess its state for administrative decision-making concerning its development and scientific and methodological support design.

The conceptual basis of distance learning, its designing and implementing is reflected in the publications of O. Alieksieiev [3], Ye. Smirnova-Trybulska [4], P. Stefanenko [5], P. Fedoruk [6], B. Shunevych [7], A. Kiv (2018) [8]. The problems of distance learning organization are raised in the dissertations of N. Zhevakina [9], O. Kravchenko [10], N. Miklashevych [11], Ye. Prokofiev [12], N. Burkina [13], Ye. Vladymyrska [14], T. Hryhorchuk [15], V. Zhulkevska [16], L. Ivanenko [17], T. Lavryk [18], V. Lukin [19], O. Khmel [20], S. Shtanhei [21] dedicated their researches to the development of techniques and usage of the distance learning technologies.

Theses analysis confirms that today in Ukraine distance education or its elements are introduced mainly in the universities' environment and are practically absent in the vocational education and training system. However, the request for it exists in the society.

The article's goal is to research and analyse the VET teachers' readiness to implement distance learning technologies in the skilled workers' and junior specialists' vocational education and training.

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2 Theoretical backgrounds

The legislative basis of the national distance learning systems are as follows: Law of Ukraine "On Education" (2017), National Strategy of Education Development in Ukraine for the period up to 2021 (President of Ukraine, 2013), Concept of Distance Education Development in Ukraine (Ministry of Education and Science of Ukraine, 2000), Regulations on Distance Learning (Ministry of Education and Science of Ukraine, 2013), etc. [22-25]. First, we will point out that we understand the concept "distance learning" in the context of interpreting the distance mode of education by the Law of Ukraine "On Education" (2017) as individualized process of education which happens mainly through indirect interaction of distant participants of education process in the specialized environment, which functions on the basis of modern psychological, pedagogical and information and communication technologies.

Thus, under the research we defined the following concepts:
- distance vocational learning is the individualized process of forming the professional competences, necessary to perform certain work or group of works, which can be carried out in the VET institutions by individual or course training in the production and service spheres; it happens through indirect interaction of distant participants of education process in the specialized education and professional environment using modern psychological, pedagogical, information and communication technologies;
- distance vocational learning technology is the ordered and systemized information and learning interaction of education subjects, which is carried out by using telecommunications, in the process of which the future specialists' professional competences forming is achieved;
- learning content management system (LMS or LCMS) in the VET institutions is the software and hardware complex which provides indirect interaction of distant participants of sustainable education process by means of automating its components and which is a part of VET institution information and education environment. The most common learning content management systems in the Ukrainian education sphere are LMS Moodle, eFront, OpenEDX, etc.

The distance education concepts are relatively young and dynamic in terms of IT, tools, methods, forms of work development and progress from the information and education point of view. It means that the teachers' readiness for distance learning implementation is multidimensional category, grounded in this context as:
- personal and professional formation, dynamic as concerns the progressive development of information and communication environment (e-systems, teaching aids and ICT) [26];
- the teacher permanently refines himself individually and in pedagogical interaction, thereby increases motivation to mastering the professional knowledge and skills, necessary to implement technological operations in the e-space; forms the ability to reflection, self-analysis on the basis of the activity results, personal and social significance awareness;
- appears in teaching by the complex of components (motivation and value, cognitive, operational and activity, evaluative and reflexive) though implementation of distance education functions (organizational, learning and cognitive, communicational, diagnostic);
- promotes effective combination of the traditional and innovative forms of learning for achieving the education goals by educators in the process of future skilled workers' professional training [27].

The components of VET teacher's readiness to distance vocational learning are: motivation and value – teacher's conscious motivation to distance vocational learning; cognitive – necessary amount and level of knowledge, skills and abilities, professional experience for making certain activity in the e-learning and professional environment; operational and active – the ability to correctly perform distance vocational learning; evaluative and reflexive – evaluating the distance vocational learning results on a reflexive basis.

3 Method

In order to implement the research goal, the adapted questionnaire for carrying out the SWOT analysis and authors' questionnaire for clarifying the VET teachers' readiness to distance vocational learning implementation were prepared. In order to ensure the statistical accuracy and relevance of the received data Google Forms web service with restricted access to the e-questionnaire (only by the link) were used. In turn, the link was spread exclusively through the regional training (scientific) and methodological centres (cabinets) of vocational education and training. It made it possible to provide the necessary number of respondents and address the questionnaire only to the target audience (to ensure the purity of the sampling).

4 Results and discussion

In total, about 3,500 VET institutions' teachers from all the regions of Ukraine took part in the e-study, the most active among which were as follows: Kyiv city (454 persons), Lviv region (395 persons), Sumy region (386 persons), Luhansk region (323 persons), Cherkasy region (298 persons) and Odesa region (266 persons).

The questionnaire was conducted by the Laboratory of Distance Vocational Learning of the Institute of Vocational Education and Training of National Academy of Educational Sciences (NAES) of Ukraine.

The questionnaire consisted of 4 groups of mostly closed questions (except for questions in Group 3):
1. A group of questions – a description of the respondent's VET institution (geography and specialization).
2. A group of questions – a description of the respondent, which included questions about age, work experience, qualification, subjects.
3. A group of questions was compiled according to the methodology of SWOT analysis. It aimed to determine the experience and expediency of using, as well as

prospects of distance learning technology in vocational education, the complexity or other problematic aspects of distance vocational learning.

4. A group of questions made it possible to determine teachers' readiness for distance vocational learning according to the developed criteria and indicators.

According to the VET institutions profiles, the teachers' participation was distributed as follows: building – 1408 persons, trade and catering – 1285 persons, transport – 1044 persons, agriculture – 1040 persons, etc. Half of the education institutions, teaching staff of which took part in the survey, had two or more profiles. According to the type of training the number of teachers were as following: vocational practical (38.4%), vocational theoretical (26.2%), social and humanitarian (16.7%), natural sciences and mathematics (12.2%), general education (3.4%) and physical (3.1%) subjects. Teachers with various qualification categories (higher – 24.7%), pedagogical titles (without title – 57.9%) and teaching experience (more than 20 years – 34.5%) took part in the study.

During the experimental work, the VET teachers' experience concerning the distance vocational learning usage in teaching was studied. Figure 1 presents the summarized answers received during the survey.

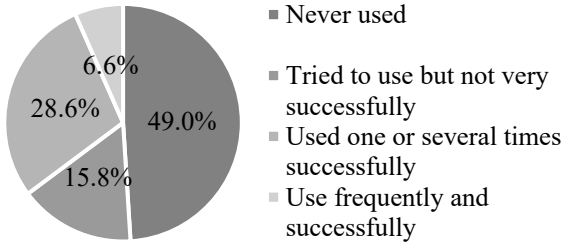

Fig. 1. Distribution of VET teachers according to the experience of distance vocational learning usage in their teaching.

So, almost half of teachers (49.0%) never used the elements of distance vocational learning in their teaching. Other half of questioned educators tried to use some elements of distance vocational learning (15.8% tried to use them but not very successfully; 28.6% – one or several times successfully used distance learning in their teaching). Almost every sixth respondent had negative experience of using the distance vocational learning (15.8% tried to use but not very successfully). Only a third part of educators (28.6% and 6.6%) had positive experience of such an activity and only 6.6% did it on the system basis and effectively. It can be argued that VET teachers use distance vocational learning or its elements occasionally.

According to the collected data, it was important to study the teachers' opinion concerning the prospects of distance learning introduction in the vocational education and training system. Figure 2 presents the summarized results.

Among the surveyed educators, the majority (28.3% answered "yes, it is perspective"; 28.4% – "rather yes") consider distance vocational learning introduction perspective and only 7.8% categorically find it inappropriate. So, two in three teachers consider distance vocational learning perspective, one in five (20.0%), on the contrary, find it rather unpromising, and one in six respondents could not decide. It is noteworthy that actually the number of those who have occasional successful experience of using the distance vocational learning – 28.6% (Figure 1) – matches those who consider distance vocational learning quite promising – 28.4% (Figure 2), as well as those with negative experience of use – 15.8% (Figure 1) and those who could not decide on their attitude towards distance vocational learning – 15.4% (Figure 2).

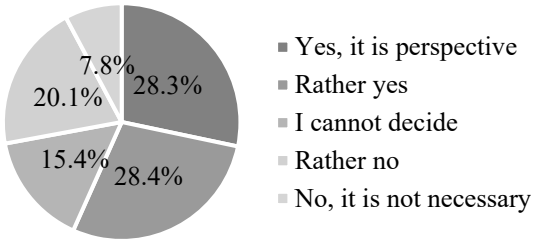

Fig. 2. Distribution of VET teachers according to the assessment of prospects of distance learning introduction in the vocational education and training system.

Similar ratios are retained in teachers' responses to the question concerning the prospects of distance learning usage on their own subjects: 24.7% – "yes, it is prospective", 26.3% – "rather yes than no", 12.3% – "I cannot decide", 21.9% – "rather no than yes", and 14.8% – "no, it is not necessary".

The relevance and promising character of distance vocational learning is confirmed by the desire of the majority of surveyed VET teachers to improve their mastering (75.0%). The number of those who consider using the distance vocational learning prospective (51.0%) is slightly lower. The number of those who could not decide (12.3%) is also lower. Almost the same is a number of those who opposite the distance vocational learning usage (21.9%), but the number of opponents of such learning (14.8%) is almost twice bigger.

According to the survey results, it is possible to conclude that the distance vocational learning problem is acute for all the vocational education and training system, VET teachers need not only scientific, but also thorough methodological support of distance vocational learning to use all the distance education opportunities fully and effectively and to achieve the highest level of readiness to qualitative organization of distance process, usage of distance vocational learning functions, distance courses design, etc.

Using the SWOT methodology in respect of the distance vocational learning technologies allowed to make appropriate summaries regarding the distance vocational learning strengths, problems, opportunities and threats.

The application of the SWOT methodology regarding the use of distance learning technologies has made it possible to generalize about the satisfaction, problems, opportunities and threats of distance vocational learning.

Thus, *the satisfaction* (strengths) of distance vocational learning can be defined as follows: organization of learning on an individual schedule; accessibility of distance courses' materials for students; rational usage of time by students and teachers; taking into account students' individual peculiarities and emphasizing their abilities' development; maximum consideration of each student's identity, creating conditions for their self-realization; providing vocational education to people with disabilities (equal access to quality education); saving time and money (economic efficiency); instant feedback between distance vocational learning subjects; direct teacher's control over the tasks performed by each student; convenience and objectivity of input and output control, which frees the teacher additional time; possibility of revising the material and composing new themes from available micro-modules; development of students' skills to work independently; stimulating teachers' self-education. In addition, teachers noted the significant development of interdisciplinary links, possibility to carry out binary lessons, round tables online, etc.; taking into account the modern trends in the life of society; providing wide opportunities for obtaining profession and speed of getting the information; increase of IT literacy, recording the material in a digital form, registering the results in an e-journal; exchange of experience of introducing the distance vocational learning in various VET institutions (organizing of webinar for acquainting with practical aspects of distance vocational learning functioning); teachers' design of e-learning materials using innovative technologies; expanding the possibilities of providing services in obtaining the vocational education for people from remote regions or other countries, etc.

Among *the weaknesses* (problems), respondents pointed the lack of VET institutions' provision with equipment and licensed software product for distance vocational learning organization; not all the teachers can master ICT; necessity of special training on distance courses design; the lack or difficulty of accessing the Internet for certain categories of students (socially disadvantaged, poor, from multi-child families, orphans, etc.); the lack of teachers' and students' readiness to distance learning technologies; absence of distance teaching technique; low level of teachers' and students' IT literacy; difficulties in passing the practice; the limited possibilities for information quick search (at the same time, the lack of knowledge how to search it correctly and effectively); difficulties in integrating theoretical and practical training (during the sustainable education process designing taking into account the need to form the practical skills); VET students' weak skills to individual work (needs high self-organization and motivation to effective distribute their own time).

Distance vocational learning implementation in Ukrainian VET institutions is complicated by the absence of technical possibilities and teachers' communication skills during webinars; insufficient level of teachers' information and communication competence development; insufficient teacher's qualification to organize distance learning. Therefore, there is a problem in designing and acquainting teachers with distance vocational learning implementation procedures, mastering the methodologies and technologies of distance courses design, conducting master classes on practical lessons, students' motivation, etc.

The respondents defined the following the *opportunities*, reserves and ways to solve the problems: instrumental, methodological and personal resources. To introduce and further use the mentioned technologies the teachers are proposed to study the experience of those education institutions, where distance vocational learning already works; combine traditional (paper) information sources with modern (electronic) ones; focus on the available tools; create and/or use the existed resources; use experience and recommendations of the Laboratory of Distance Vocational Learning of the Institute of Vocational Education and Training of NAES of Ukraine, results of researches or independently work out the necessary experience.

There are problems that the VET institutions cannot solve on their own: the availability of licensed software; the absence of techniques and technologies of designing learning materials, tests, future skilled workers' competences assessment system, creating professional video and audio materials, etc.

Among *the threats* of distance vocational learning the following were defined: rejection of distance vocational learning by separate categories of students; quick renewal of information and technologies (production technologies develop faster than teachers can design the distance course); appearance of technical problems and absence of access to Internet for some students at home; low level of teachers' and students motivation to virtual environment activity, their psychological unreadiness; insufficient number of e-resources on the subject taught distantly, etc. Separately the need for large investments and teachers' time expenditures on distance courses preparation and the absence of mechanisms of such work funding is pointed out.

To solve the identified problems concerning the distance vocational learning technologies using in the VET institutions the Laboratory of Distance Vocational Learning of the Institute of Vocational Education and Training of the NAES of Ukraine organized the scientific and practical web-seminar "Using the LMS e-learning.org.ua in the Vocational Education and Training Institution's Education Process" (2016), 1st and 2nd all-Ukrainian web-conferences "Theory and Practice of Distance Learning in Vocational Education and Training" (2017, 2018). During these events a common discussion on actual problems took place, and therefore, the directions of solving the existing difficulties in the context of distance vocational learning realization were outlined. For example, the proceedings' detailed analysis allows to state many positive aspects in improving teaching on the basis of distance learning with full usage of combining the distance technologies with traditional opportunities. Along with the benefits of distance learning, practitioners define problems, namely: technical and methodological problems concerning e-platforms usage; much time spent on distance courses design, review, complementation, renewing the didactic, electronic, testing learning tools, etc.; difficulties with self-registration of participants in the

distance learning system; incomplete use of all the opportunities of web-oriented education process support system LMS Moodle; mismatch of organizational and technical provision to the of e-platforms' functioning; imperfection of methods of using IT in education process; the need to train teachers to use IT in traditional and distance learning; the need to increase the teachers' motivation in relation to ICT using (problem solving: courses, master classes, constant improvement of teacher's competence level, experience exchange); improving the control criteria in the distance learning process [28, 29].

Analysing the SWOT analysis results content, especially in terms of threads, and taking into account practical difficulties, which arise during distance vocational learning organization in the VET institutions, there is an urgent need to solve the problem of teachers' readiness continuous development to introduce distance learning technologies based on predefined components.

The experiment's confirmatory stage results concerning the teachers' readiness to implement distance vocational learning according to the components are evidenced by the following data: motivation and value component: high level – 40.5% of respondents, sufficient – 36.7%, average – 12.4%, low – 10.5%; cognitive component: 5.6%, 31.5, 37.4, 25.5% respectively; operational and activity component: high level showed – 8.6%, sufficient – 26.3%, average – 26.8%, low – 38.3%; evaluative and reflexive component: 22.0%, 52.2%, 22.5%, 3.2% respectively.

The general distribution of the VET teachers according to the levels of readiness to implement distance vocational learning is presented in Figure 3.

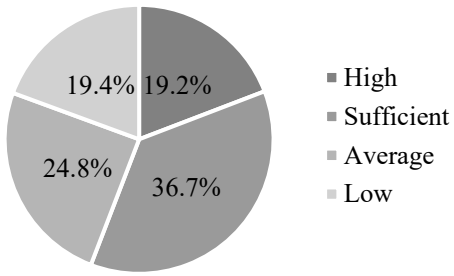

Fig. 3. Distribution of the VET teachers according to the levels of readiness to implement distance vocational learning.

The analysis of the received empirical data shows the prevalence of VET teachers with sufficient level of readiness for distance vocational learning. At the same time, the motivation and value, evaluative and reflexive components have the biggest demonstration in the general level of readiness, the level of cognitive and operational and activity components is smaller. This is evidenced by the fact that VET teachers in general are positively motivated and directed to distance vocational learning implementation. Under such circumstances the value of teacher's systemic innovative self-development, expansion of the cognitive sphere with new knowledge, information, methods and mechanisms, their productive transformation in the distance education environment increase. The optimal combination of traditional, innovative, distance, intuitive learning technologies by teachers ensures not only self-development of a modern teacher, but also helps to achieve the desired results in the skilled workers' and junior specialists' training in VET institutions.

5 Conclusions

So, based on the research results and analysis of teachers' readiness to implement distance learning technologies in the skilled workers' and junior specialists' vocational education we found that in the practice of skilled workers' and junior specialists' vocational education only some fragments of distance vocational learning are used. Partially distance vocational learning is introduced in different ways and using different methods, depending on material and technical capabilities of the VET institutions, level of teachers' mastering of IT tools and web-technologies. Most VET teachers recognize the promising character and expediency of system implementation of distance technologies in the process of concrete subjects teaching (general education, general vocational, vocational theoretical).

At the same time, the problems in using distance vocational learning related to technical and material provision that causes difficulties in distance vocational learning organization were found, qualitative functional usage of e-platforms; distance courses design; low level of students' and teachers' IT literacy that complicated the introduction of distance learning technologies; integration of theoretical and practical training in the conditions of distance learning (designing sustainable education process taking into account the need to form practical skills); organization of students' independent work (need high self-organization and motivation to distribute one's own time effectively); mobility and flexibility (training student to distribute their capabilities properly), etc.

The analysis of the current conditions of distance learning in the VET system shows that it is essential to implement it to train skilled workers for certain sectors of economy. However, the level of development of individual components of teachers' readiness to work with distance learning indicates the need to organize their training both in the system of advanced training and in the organization of methodical work. At the same time, the content of each component (motivation and value component, cognitive component, operational and activity component, evaluative and reflexive component) of teachers' readiness to implement distance vocational learning can be used to develop a programme of training teachers for using information technologies in vocational training of skilled workers in the organization of methodical work in VET institutions. The applicable nature of the research lies in this very aspect.

The desire of VET teachers to solve the problems of distance vocational learning is confirmed by high indicators of motivation and value and evaluative and reflexive components formation for their readiness to implement distance vocational learning, under conditions of increasing the indicators of cognitive and operational and activity components of readiness, on the development

of which today scientific and methodological activity of the Laboratory of Distance Vocational Learning of the Institute of Vocational Education and Training of NAES of Ukraine through the organization of trainings, distance courses on a modular basis, scientific and practical web-seminars and web-conferences using the Institute's Learning Management System (http://e-learning.org.ua/), preparation and publication of research papers, scientific and methodological, information and analytical materials, etc. are coordinated.

The received research results and survey data analysis, the teachers' experience outlined the ways of scientific solution of existing problems, summarized prepared methodological recommendations for improving the process of distance learning implementation in vocational education and training [30].

Definitely, the implementation of theoretical and methodological developments regarding the development of distance education, training, technologies requires consolidation of efforts of the scientific community with all the stakeholders of the processes of distance education system development. Under these circumstances, the following suggestions for solution are outlined:

- at the national level – regarding the regulations support of the VET institutions students' distance vocational learning, i.e. the Regulations on Distance Learning (Ministry of Education and Science of Ukraine, 2013) should be renewed defining the goals and tasks, peculiarities of vocational education organization, normalizing the load and funding of distance mode of learning;
- at the regional level – regarding the creation of information education environment as a multidimensional data structure for the exchange of information in the region, the informatization of information flows for optimal administrative decision-making concerning ensuring the regional labour market needs with skilled workers, junior specialists and specialists with higher education;
- at the VET institution level – regarding the assistance in teachers' preparation to use the distance vocational learning through the in-service courses, in the methodological work system, during the intercourse period of professional development using various forms of self-education; creating the necessary material and technical, organizational, psychological and pedagogical, didactic conditions, appropriate training and methodological assurance of distance vocational learning; monitoring the effectiveness of distance vocational learning usage in subjects' teaching.

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Methodical requirements for training materials of on-line courses on the platform "Higher school mathematics teacher"

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Abstract. The article looks into the issue of developing methodical requirements for the structure and content of online courses. The study is dedicated to the analysis of peculiarities of developing the content of online systems and developing methodical recommendations to educational materials for online courses of training higher school mathematics teachers. The research considers the experts' experience in preparing, structuring and developing the content for online courses and answers to volunteers who have agreed to test the educational materials of the course. The answers given by the participants have allowed estimating the quality of the developed course and detecting its insignificant drawbacks. The article discusses general requirements to the structure and content of the online course, means for the implementation of a testing subsystem, peculiarities of developing educational video content and educational materials in PDF format, issues of implementing forum and survey subsystems, as well as means of estimating learning outcomes. We have grounds to conclude that the quality of the course is determined by the range of factors, among which we point out the course organization based on weekly planning, implementation of a testing subsystem under conditions of extended functionality, creation of abilities to organize feedback.

1 Introduction

1.1 Problem statement and its topicality substantiation

Achieving sustainable development through on-line education is the key to a better and more sustainable future for everyone. The implementation of the idea of open online education requires the development of recommendations both as technical and methodical support of online courses; and thanks to them a considerable number of people can increase their qualification or develop professional expertise. Supporting the idea of available educational opportunities, we have created the educational platform Higher School Mathematics Teacher [1] that offers mathematical and educational – methodical online courses and we have studied experts' experience in preparing educational materials. By implementing numerous recommendations concerning the preparation, structuring, and development of the content for online courses, Writing and Structuring Online Learning Materials [2], DIGICOMP [3] and Leicester Learning Institute [4] remind that we live the life of constant changes and these changes have to influence teaching and learning. In order to implement these changes in the system of online education, we have to provide educational materials that live up to the students' expectations. This means that giving learners the possibility to acquire some particular skills via online courses requires serious training. Therefore, the actuality of the problem of developing methodical requirements for the structure and content of online courses is not questionable.

1.2 Analysis of the latest researches and publications

In order to start the development of online course "Methods for teaching mathematics to students in technical universities" [5], we have studied practical recommendations by B. Ghirardini [6] who considers that the development of any course has to encourage the creation of a community of practitioners and support their willingness to cooperate. While planning the development of materials necessary for implementing particular kinds of work we paid our attention to the possibility to plan the achievement of educational outcomes. At the stage of planning the aims, we were focused on the concept of the platform Higher School

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Mathematics Teacher, developed by K. Vlasenko et al [7]. Taking into account scientists' opinion while preparing curriculum we were focused on achievable goals, believing that the achievement of aims by the student on a regular basis will encourage their motivation to aspire to more. While developing the lectures we were interested in the research by C. J. Dommeyer et al. [8], D. J. Deming et al. [9] and M. Bauer [10], who describe in their works the improvement of lecture materials using the questionnaire of respondents who work with courses. E. Cruse [11], A.-M. Suduc et al. [12, 13] recommend giving lectures using video. Confirming the efficiency of using videos in the educational process, among the greatest advantages of its using the scientists emphasize the possibility of course participants to learn the material according to their pace of assimilating the educational materials. Moreover, in scientists' works, there is evidence that video content ensures a greater emotional impact on participants in comparison to the text-based one. Developing tests that according to C. Suwatthipong et al. [14] have to accompany learning theoretical materials we considered scientists' opinion that testing should both help to estimate the level of success while assimilating the educational material and help to acquire new knowledge. Being acquainted with the research in which C. Wrigley et al. [15] compared the content quality of Massive Open Online Courses; we came to the conclusion that while developing course materials it is necessary to evenly distribute labour intensity of students' learning activities by weeks, providing the interaction among the participants. Furthermore, we took into consideration the results of the research by B.-A. Jönsson [16], and K. Vlasenko et al. [17], where it is justified that the efficient online course includes the integration of various web tools and resources for learning the course material.

Thus, giving recommendations to the presentation of educational materials for online courses, every scientist stated that there should its approach for the development and certain nuances should be considered. So, the article is aimed at carrying out a theoretical analysis of the peculiarities developing online system content and methodical requirements to educational materials for online courses of training higher school mathematics teachers.

2 Method

We have carried out a survey among master students (the qualification code of the program "014.04. Secondary Education. Mathematics") and higher school mathematics teachers to find out the quality of educational materials of online course "Methods for teaching mathematics to students in technical universities", published on the platform "Higher School Mathematics Teacher" [5]. The theoretical analysis of the researches and resources that implement the recommendations, content structuring and development for online courses and analysis of respondents' answers to survey questions published on the platform forum has influenced the description of the methodical requirements to structure and content of online courses. To explore the resources (Table 1), we used the Inductive Content Analysis Method, which helped us review the structure and content of the most popular Massive Open Online Courses (MOOC). When selecting resources, we focused on the online courses included in the Top Tools for Learning 2019 [18].

Having analysed the resources, we found out the number of sections that the on-line courses include and the average course duration. We were eager to know how often titles are offered and for what purpose testing in courses is used. We have highlighted the peculiarities of video lectures, training materials in PDF format. Particular attention was paid to how feedback from students, taking the course is organized. Through content analysis, we have developed methodical requirements for educational materials for online courses of training higher school mathematics teachers.

2.1 General requirements to the structure and content of the online course

Following the recommendations of dividing online course content into sections, subsections (topics), pages and components, we have built a course "Methods for teaching mathematics to students in technical universities" based on weekly planning, where sections are formed on the principle of combining materials that are learned during one or several weeks.

We have also considered that educational methodical online courses have to include no more than 6 sections. Every section has to include one or more pages; the page has to have no more than one component. In addition, while developing the courses we stuck to the following recommendations related to their structure.

1. We divided the materials of the course into logical sections of the length corresponding to learning during 1-2 hours ("blocks" of education).
2. For every section, subsection and page we gave clear descriptive headings. It will help students to plan over which sections they will work in every chapter and allow them to review the topics that have already been studied.
3. At the beginning of every week and every new section we gave a review of materials including structure, learning outcomes and approximate learning time. In addition, we gave the previous test at the beginning of every section.

2.2. The implementation of the testing subsystem

In order to implement the testing subsystem on the platform a program application for extending functionality was used – the plugin "WP-Pro-Quiz" that ensures flexible settings of responses' options and provides related information.

While creating test questions it is stipulated that information about the number of points for the right answer is provided and the type of answer (single choice,

multiple-choice, open choice, etc.) is indicated. Also, there is a possibility to add hints to a particular question. After creating and setting up the test it is possible to publish it on any page of the online course using special shortcodes.

During the online course, the test is considered passed in case of giving 60% right answers by the participant.

After the test the participant can look through the number of right answers and time spent on taking it.

Table 1. Analysis of the structure and availability of educational materials of MOOC.

Online courses	The number of sections that the online course includes	Average course duration, hours	Titles are used	The availability of subsystems for testing	The availability of the video lectures	The availability of educational materials in PDF format	The availability of communications tools
LinkedIn Learning [Lynda] [19]	4-7	2-28	For every section	For evaluating the learners' achievement	For presenting theoretical material	Not used	Feedback form
Udemy [20]	4-12	18-40	For every section	For a current check on the learners' practical skills	For presenting theoretical and practical material	For presenting training tasks	Feedback form
Coursera [21]	4-6	10-30	For every section, subsection	For evaluating the learners' achievement	For presenting theoretical material	For presenting training tasks	Forum
edX [22]	4-5	12-20	For every section, subsection and page	For a current check on the learners' practical skills	For presenting theoretical material	For presenting theoretical material and training tasks	Forum of the week
FutureLearn [23]	4-6	2-15	For every section, subsection and page	For evaluating the learners' achievement and for a current check on the learners' practical skills	For presenting theoretical and practical material	Not used	Discussion board

2.3 Peculiarities of developing educational video content

According to the recommendations, materials of the online course can consist of video files, hypertext, demonstrative animation, audio lectures, video lectures, schemes, images, graphics, tables, drawings, information reference material, computer simulators. Also, presentations and other extra materials such as attached files and interactive supplements, sources that are given in the reference list can be used.

We use video content to get participants acquainted with the aims and resources of the course as well as highlight particular topics. Video lectures focus on the main moments of learning material, disclose the topic of the material, and summarize the main conclusions. While creating video lectures it is expected to highlight semantic blocks (video clips) lasting from 3 to 10 minutes that will be watched by the participants during the online course. The image should be high -quality, the text that is demonstrated on the slides should be available for reading from the mobile device screen. Pure sound requires minimal background noise, clear pronunciation of words and constant level of volume. While creating video lectures it is preferable to use the universal format of video files in MP4 format.

In order to create videos during the online course "Methods for teaching mathematics to students in technical universities", we used software Camtasia which implements capturing the video from the screen. Among the main functional abilities of this video editor, which is used while developing educational video, we can highlight providing the recording of the image from the screen including recording sound effects from the microphone or speakers and editing a new video without installing additional software.

In order to publish video content on pages of the online course, we used the video from the file directly on the administrator's panel of the electronic platform without involving extra services. Using such a method of integration ensures the possibility to control the size of the video player and to add extra settings.

2.4 Peculiarities of developing educational materials in PDF format

In order to give the main theoretical information on the topics during the online course, we use educational materials in PDF format that ensures compatibility and absence of distortions in published materials of the course. Moreover, using PDF format allows the participants to download educational materials to their proper computers for a further acquaintance without any preview on the web-page.

While creating educational materials in PDF format it's necessary to follow the requirements for presenting documents: to use headings, lists, images with sighs, to present table data in the form of tables. In order to type text material the direct (regular) font, which ensures

easier perception of information, should mainly be used. The main text should be aligned to the page width. It is not recommended to use formatting with the help of indent and tabulation, multi-column page making, blank line.

While using hyperlink it is necessary to consider that all hyperlinks should be represented as a text in the sentence to increase readability.

It must be noted that while preparing educational materials published on the platform during online courses, we use the logo of the public organization "Smart Maths".

2.5 Forum implementation

During the course "Methods for teaching mathematics to students in technical universities", the feedback with course participants is organized using thematic forums. Participants' part in the weekly forum gives them a possibility to express their proper opinion using discussion questions that concern the main topics of the course.

Together with the forum use the organization of participants' communication takes place in asynchronous mode, in other words during a long period. Participants can sign up for the forum to get notifications about new topics and answers on the forum. With the help of the forum, there is a participants' discussion of their classmates' works, which is outlined by one of the course tasks. Furthermore, participants can use the forum to share examples of their work and to ask each other questions and the teacher concerning the studied topics.

Forum implementation on the platform "Higher School Mathematics Teacher" was carried out using plugin "wpForo" that consists of a set of the main tools for managing the forum. The main advantages of using the plugin are flexible settings of the forum presentation, creation of convenient user's profile and the possibility to add particular supplements to extend the functionality.

2.6 The implementation of the survey subsystem

An important element while developing an online course is using surveys that ensure the teacher's possibility to ask participants questions and offer a wide range of possible answers. While creating a survey the teacher describes a certain situation and formulates a question encouraging participants to express their opinion. The survey final result is the percentage of participants who chose one or another answer.

During the course "Methods for teaching mathematics to students in technical universities", surveys are created with the help of service Google Forms and are used as voting for theme selection as well as for discussion over course materials.

The choice of Google Forms as a tool for creating surveys is explained by the following characteristics: availability of the created survey for the respondents just after its publication, possibility to edit it, opening for getting answers and closing after finishing the survey. Furthermore, there is a possibility to integrate forms for surveys on the online course page. In order to show the survey results the service generates automatically the electronic table, there is an option to review respondents' answers in the form of diagrams and graphics with statistical information in high-quality and percentage format.

2.7 Peculiarities of evaluating educational outcomes

Within the course "Methods for teaching mathematics to students in technical universities", we assume to have peer assessment to estimate the performance of training activities. While using such type of evaluation, we followed the recommendations regarding the development of the criteria table. We took into account that requirements to tasks have to be clearly defined and encourage the author (later reviewer) to pay attention to different sides of work. The process of writing a piece of work that corresponds to the requirements and the process of checking such works is useful for participants, as it develops skills of giving constructive criticism including negative.

For every task, the course tutor developed the evaluation criteria with a detailed description of the necessary content on every criterion for getting a particular mark. As a tool we offer to use Google Drive services to complete the task; it ensures the possibility to store completed works by implementing shared access to the documents and Google Forms to implement the feedback with participants.

Successful learning of the educational material of the course is completed by getting a certificate. The criteria of getting a certificate are based on criteria – oriented approach that includes the comparison of educational achievements of every participant with planned learning outcomes.

3 Results

To carry out the analysis of the correspondence level of the course content "Methods for teaching mathematics to students in technical universities" to specified requirements of developing online courses, we held a survey among the participants. Respondents were offered to answer a survey using the forum on the platform "Higher School Mathematics Teacher".

68 volunteers who agreed to test educational materials of the course took part in the survey. Participants' answers allowed evaluating the quality of the developed course and determining minor gaps in the implementation.

We offered them to range the quality of presenting information concerning the structure and semantic content of the online course on a scale from 1 to 5 where 1 is the minimal parameter estimate, 5 is the maximal one. Table 2 provides the survey results.

Analyzing the histogram data we concluded that most volunteers have highly estimated the structure and quality of the developed content of online courses giving

4 or 5 points. In respondents' opinion presenting information concerning the course program, its duration and frequency of classes were fulfilled most successfully. Among the types of educational content materials in PDF format and video lectures got the biggest number of maximal points. So, presentation of the structure of the online course and quality of developed educational materials correspond to given requirements.

Table 2. Results of testing educational materials of the course "Methods for teaching mathematics to students in technical universities".

Questions	Respondents' answers				
	1	2	3	4	5
Accessibility of information presentation concerning the aims and purposes of the course	5	8	10	27	18
Accessibility of information presentation concerning the duration and frequency of the course	3	4	13	23	25
Accessibility of information presentation concerning the target audience of the course	6	3	11	28	20
Accessibility of information presentation concerning the course program	1	6	9	25	27
Convenience of the navigation system during the course	8	9	15	24	12
Quality of presenting educational materials as video lectures	1	4	7	29	27
Quality of presenting educational materials in PDF format	2	6	12	23	25
Quality of tests	3	5	14	26	20
Quality of survey implementation among course participants	4	7	16	21	20
Quality of peer-assessment implementation	4	8	14	20	22
Quality of feedback implementation using the weekly forum	5	8	18	19	18

The ranking results are presented in the form of a histogram (Fig. 1).

Moreover, participants were offered to evaluate general impression from the online course "Methods for teaching mathematics to students in technical universities" (Fig. 2).

According to the survey results, 68% of respondents believe that the course is developed at a high level, 25% have estimated the course development at a sufficient level and 7% marked that the course requires further development. Among the recommendations given by the respondents concerning the improvement of the online course, we can note the wish to include the final test to evaluate the results of learning activities and modernization of navigation system to the course program.

4 Discussion

The analysis of the research by L. Cuesta [24], S. J. McGahan et al. [25] and work experience of APass Educational Group [26] developing online courses have confirmed our point of view about the influence of the quality of developing materials for online courses on motivation and success during the course. We agree with the point of view given by L. Cuesta [24] who emphasizes the necessity of constant analysis and evaluation of such parameters as the formation of learning content, interaction among course participants. We support the conclusions given by S.J. McGahan et al. [25] about the importance of developing methodical requirements to the content of online courses as the main tool of its quality evaluation.

The recommendations provided by the APass Educational Group [26] are very important for our research; they offer to provide the efficiency of the educational aim of the course using the following means: clear purpose presentation; match of the aim with students' expectations; direct responsibility between educational aims and students' actions during the course and their evaluation; learning materials selection and technologies that correspond to the education aims, motivate the student and support their progress; content accessibility for all students.

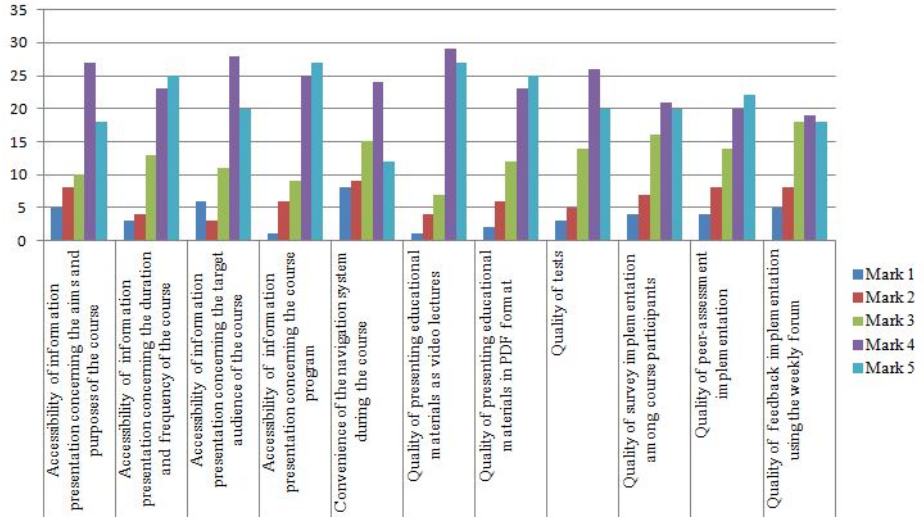

Fig. 1. Results of testing educational materials of the course "Methods for teaching mathematics to students in technical universities".

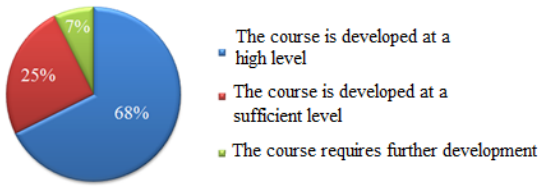

Fig. 2. The general impression from the online course "Methods for teaching mathematics to students in technical universities".

We have got acquainted with the accomplishments by N. I. Scagnoli et al. [27], D. Morrison [28], M. Puzziferro and K. Shelton [29] when we started developing video lectures. These scientists' works are dedicated to studying students' point of view concerning the use of video lectures in online classes. So, during the development of video lectures we were focused on scientists' recommendations. These recommendations were the following: to consider students' needs; to plan thoroughly and integrate in a balanced way video lectures with other course materials; to use multimodal information delivery; to create the sense of cooperation with the content through students' control over the media and teachers' presence.

Acquaintance with students' evaluation via Camtasia [30] as one of the most available programs of editing and creating video has proved the relevance of the choice of this program for presenting course content. Screen recording with the addition of necessary effects helped us in a quality new presentation and documents in PDF format. The involvement of such type of materials got approval from forum participants. During the course presentation and every week, we encourage students to take an active part in forums. This approach corresponds to the conclusions given by T. Martin-Blas and A. Serrano-Fernandez [31], who prove that participants who take an active part in forum discussions tend to get higher marks and show a higher level of learning educational material in comparison to those who did not use the forum.

5 Conclusions

The relevance of the problem of developing methodical requirements to the structure and content of online courses arises from the fact that the quality of education using online courses depends on the quality of content development. Educational materials have to be interesting, correspond to students' expectations and encourage motivation during the course. The content development requires thorough planning and balanced integration with other course materials. Testing during the course should have both controlling and educational functions. The creation of course content should be accompanied by evaluation of students who help to evaluate the quality of the developed educational materials and detect gaps.

Based on the analysis of current recommendations regarding the development of online courses, as well as considering the results of students' and mathematics teachers' survey we have described the methodical requirements to the structure and content of online courses. The course is based on weekly planning, the test subsystem is implemented under extended functionality, and abilities to organize feedback are integrated. While planning online courses it is necessary to plan properly and organize feedback with course participants. The feedback allows detecting both positive aspects and gaps, drawbacks that were detected during project planning and implementation.

The possible way of implementing feedback is the creation of several theme forums where there is a possibility to exchange information among the listeners.

The results give a possibility to define several directions for further research, among which the implementation of online resources usability.

We are grateful to everyone who has taken part in the survey.

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Usability analysis of on-line educational courses on the platform "Higher school mathematics teacher"

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Abstract. The article addresses the issue of implementing the usability principles of educational internet resources. The paper debates the latest researches on the question concerning the search for the factors that influence the results of online education. The analysis, which we carried out, allowed us to focus on such known six criteria of usability design as Information Quality, System Navigation, System Learnability, Visual Design, Instructional Assessment, and System Interactivity and suggest the existence of the seventh criterion named Responsiveness. The research considers the principles of usability implementation following the example of the open platform of online education "Higher School Mathematics Teacher". The answers given by 203 respondents during the survey allowed defining the direction of implementing the usability criteria on the platform. We were eager to know the opinion of teachers and students, who became the first users of the platform. The article discusses the criteria implementation while developing online courses on the platform. There was ground to conclude that when designing on-line platform courses, all seven usability subcategories are important.

1 Introduction

1.1 Problem statement

Developing on-line courses is one way to a sustainable future for our society through education. The modern market of online education offers a great number of online courses for educating adults, young people and children. The subject matter and complexity of such courses differ a lot, but certain development principles and operation of educational internet resources have a lot in common. One of the most important questions while developing any of the sites is its usability. This term is used as a measure of site friendliness, its understandability, and naturalness for the user. Web-site usability is determined by simplicity. Simplicity makes internet resources easy to perceive by users, makes it possible to carry out a fast shift to the necessary content and facilitates access to information. Therefore, the research of usability issues in educational software is an important aspect of developing distant education.

1.2 Analysis of the latest researches and publications

While searching for the factors that influence the results of online education, scientists paid attention to the interface of educational platforms. J. Nielsen [1] was one of the first scientists who used the term usability. He developed a heuristic evaluation – methodology of researching the software usability. So-called "Nielsen protocol" consists of ten heuristics developed for the software:
- The user can detect the system status;
- The system uses the terminology, which is convenient for the user;
- Free system manageability, support of removal function (undo) and repetition function (redo);
- Consistency and standards;
- Error prevention and warning the user about further problems;
- Load minimization on the user's memory;
- Flexibility and efficiency of the usage;
- Aesthetic and minimal design;
- The system has to offer the user a constructive solution to the issues that arise;
- Presence of reference information in the system.

T. Reeves et al [2] increased the number of heuristics up to fifteen when they developed them specifically for electronic education. While designing the systems of electronic education, the scientists S. C. Srivastava et al [3] proved that the attention should be focused on the learning outcomes and not only on satisfying users' interests. The interface has to be attractive and simple to use, but its main task is to give possibilities to the user to build his/her own strategy of education. D. Squiresa and J. Preece [4] offered an approach that integrates the idea

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of heuristics of software usability with the idea of considering the educational results and issues. In scientists' opinion, the main criterion of developing electronic education has to become its reliability. M. Asarbakhsh and J. Sandars [5] named the usefulness of technologies and their usability among the significant factors that should be considered while developing and implementing technologies of online education.

While highlighting and describing six criteria of usability design, A. Alshehri et al [6] formulated and carried out the research of these criteria concerning their importance for students:

1) Information Quality (IQ),
2) System Navigation (SN),
3) System Learnability (SL),
4) Visual Design (VD),
5) Instructional Assessment (IA),
6) System Interactivity (SI).

While ascertaining if this list of criteria could be considered full taking into account the possibility to use mobile devices by users, we addressed the statistics data [7]. It is clear from the data that 58% of site visits were from mobile devices. 44% of users of mobile devices visited the sites of the category "Career and Education" and 42% visited the sites of the category "Science". Using the service Google Analytics [8] we detected that 35% of users of the platform "Higher School Mathematics Teacher" [9] also use mobile devices. So, while analyzing the statistics we can say that the pattern of growth of website visitors from mobile devices will be kept in the future. Taking this fact into account we considered it necessary to introduce an additional seventh criterion "usability design" for educational web systems called Responsiveness (RS) that would reflect usability for visitors from mobile devices. The relevance of this assumption was checked in the research results.

This article is aimed at analyzing the approaches of online courses developers to implement usability, showing usability implementation principles following the example of the open platform of online education "Higher School Mathematics Teacher".

2 Methods

We used the Inductive Content Analysis Method during the research. With its help, we carried out the analysis of the structure and principles of constructing the most popular world and domestic systems of online education by highlighting seven parameters of educational platform usability. These parameters were included in the survey of higher school teachers and students. The survey was aimed at getting the evaluation by respondents concerning the usability and simplicity of online courses on educational platforms that are used by the respondents. The survey was divided into two parts. In the first part, there were questions concerning the information about the respondents, such as sex, age, status (teacher, student), their experience of using online courses and educational platforms on which they took online courses, and the aim of online education. This information was gathered to get descriptive statistics of research selection and selection of educational online platforms for the analysis. The second part of the survey included the questions concerning relative importance (value) of the determined usability categories and subcategories and category ratings for users. This section included 35 elements divided into seven parts. We had to determine the category place from 1 to 7 depending on its impact on the platform usability (where 1 is the most important). Getting a smaller evaluation rate of the corresponding feature of usability demonstrates its greater importance for teachers and students during the online course. Subcategories have to be evaluated using a 3-point scale where "–1" affects the criterion, "0" does not affect the criterion at all, "+1" has a positive effect on the criterion.

The survey was held directly by tutors of the educational online platform "Higher School Mathematics Teacher" in higher schools. 246 participants took part in the survey, among them 85 teachers and 161 students of Donbas State Engineering Academy, Institute of chemical technologies of Dahl East Ukrainian National University (the town of Rubizhne), Kryvyi Rih State Pedagogical University, Donbas National Academy of Civil Engineering and Architecture. It must be said that 43 participants (18 teachers and 25 students who constituted 17, 4% of the respondents) stated that they had never used online education. Therefore, the final number of respondents is 203 participants – 67 teachers and 136 students.

Research conclusions reached by K. Vlasenko et al [10], and the analysis of the results of teachers and students' survey allowed determining the direction of implementing usability criteria on the platform "Higher School Mathematics Teacher" [9]. First of all, we found out how we can implement the criterion Information Quality (IQ) that describes the information correspondence in the system to learners' needs and the criterion System Learnability (SL) that characterizes education simplicity and rapidity. The quality of these criteria depends on the tutor's competence that creates and supports the online course. In order to create high-quality content following the criteria IQ and SL, the tutors of the platform "Higher School Mathematics Teacher" [9] are given a possibility to use software tools to format the text, insert graphics, video- and audio information, insert links, formulas, tests, surveys. K. Vlasenko et al [11] described the application use during developing the educational online platform.

The criterion System Navigation reflects the quality of navigational tools. On the platform, it is formed with the help of main and additional menus that are posted at the top of the interface and are present on every page. Their presence allows the user to navigate to the necessary section. In order to provide a clear sequence, "breadcrumb" navigation is posted on the pages and allows representing visually the hierarchy of top-level pages and navigating all over them. The presence of such an element is especially important when there are a great number of pages that are put one in another. Ease of navigation is also provided by the presence of links directly in the content of the educational text.

The criterion *Visual Design* reflects the aesthetics of displaying the educational system. In order to ensure

readability and aesthetic design the following basic color scheme in the RGB model coding was determined: light colors for the body (#FFFFFF, #F0EAEE), dark color for the main content (#333333) and additional colors for structural elements for links (#993333, #B8999F, #D6DDE3). The general structure of the platform interface includes header, footer, sidebar and content layout elements. This structure corresponds to the purpose of the platform information content. Typography was chosen in order to provide the text and it includes the text without any notches, particular style display for headings, subheadings, and the main text.

The criterion *Instructional Assessment* reflects the simplicity and efficiency of evaluation tools. This criterion is provided using feedback forms, subsystems of testing, survey and file downloading. Feedback forms are used both for educational and general questions.

The criterion *System Interactivity* reflects the presence of simple tools of interaction among participants of the educational process. In order to correspond to this criterion the forum of the platform users that ensures the interaction student-teacher, teacher-student, and student-student was implemented.

The criterion *Responsiveness* reflects the quality, aesthetics of system display on mobile devices that have different resolution. In order to ensure the adaptability of platform design, methods of the interface presentation using stylization CSS for particular separate capabilities of the devices are used. The elements of the menu and sidebar interface have a particular view on mobile devices. Text size, headings and subheadings, links, buttons, image size and other interface elements were adapted to correspond to this criterion.

Localization and customization are also important in order to implement usability. The adaptation of mass products on demand of a particular customer on the educational platform "Higher School Mathematics Teacher" takes place through partial content change following a particular request, additional staffing of the course with extra activities and materials. Platform tutors monitor regularly discussions concerning the courses on "Teachers' forum", react promptly to offers made by the users of the course. The development of new courses is also based on studying requests and wishes made by platform users.

3 Results

We offer to consider the division of respondents according to their age and sex in Table1.

Table 1. Division of respondents according to their age and sex.

Characteristics	Teachers		Students		Total	
	number	%	number	%	number	%
sex						
male respondents	35	52,2	84	61,8	119	58,6
female respondents	32	48,8	52	38,2	84	41,4
age						
under 30	3	4,5	136	100	139	68,5
31-50	42	62,7	0	0	42	20,7
over 50	22	32,8	0	0	22	10,8

According to the survey results in Table 2, the majority of respondents (70,9 %) studied the online courses in higher schools developed with the help of the distant learning system Moodle. Furthermore, the respondents used the platforms Prometheus [12], EdEra [13], The Open University [14], Edx [15], Coursera [16], Intuit [17] for education (respondents had a possibility to name several educational resources).The aim of the education determined by the majority (68,9 %) was the current education; moreover, skills development – 23,8 %, acquiring additional skills – 3,1 %, personal development – 4,2 %.

Table 2. Online platforms where respondents studied.

Online platforms	Teachers		Students		Total	
	number	%	number	%	number	%
Moodle-based LMS	14	20,9	130	95,6	144	70,9
Prometheus	8	11,9	2	1,5	10	4,9
EdEra	16	23,9	-	-	16	7,9
The Open University	4	6,0	1	0,7	5	2,5
Edx	4	6,0	2	1,5	6	3,0
Coursera	18	26,9	-	-	18	8,9
Intuit	7	10,5	5	3,7	12	5,9
Other platforms	4	6,0	3	2,2	7	3,5

We offer to consider the categories and subcategories from the other survey part. We have found out the importance of the defined categories and subcategories for users, their usability and rating.

Category 1 – Information Quality (IQ), subcategories:
1.1 Ease of navigation
1.2 Navigation support
1.3 Reference reliability
1.4 Understandability of action sequence
1.5 Ease of access

Category 2 – System Navigation (SN), subcategories:
2.1 Ease of education
2.2 Reference predictability
2.3 Education without any initial preparations
2.4 Formulation clarity
2.5 Sufficient online assistance

Category 3 – System Learnability (SL), subcategories:
3.1 Readability
3.2 Design aesthetics
3.3 Layout information content
3.4. Presentation structure
3.5 General course consistency

Category 4 – Visual Design (VD), subcategories:
4.1. Information correctness
4.2. Information conformity
4.3 Information completeness
4.4. Ease of information understanding
4.5 Information timeliness

Category 5 – Instructional Assessment (IA), subcategories:
5.1 Evaluation tools efficiency
5.2 Ease of using evaluation tools
5.3 Reality of achieving learning objectives

5.4 Accessibility for material understanding
5.5 Feedback Information content

Category 6 – System Interactivity (SI), subcategories:

6.1 Efficiency of communication tools
6.2 Implementation of communication between the tutor and student
6.3 Possibility of communication "student – student"
6.4 Interaction organization
6.5 Feedback speed

Category 7 – Responsiveness (RS), subcategories:

7.1 Flexible layouts (website layout that will dynamically resize to any width)
7.2 Flexible images (scalable images)
7.3 Flexible media (scalable images, video and other formats)
7.4 Flexible menu
7.5 Flexible navigation

The results of respondents' evaluation of usability criteria are provided in Table 3.

Table 3. Respondents' evaluation of online education systems according to Usability design criteria.

Systems of online education	Criteria						
	IQ	SN	SL	VD	IA	SI	RS
Moodle-based LMS	1,31	2,3	3,17	3,99	6,11	6,87	4,56
Prometheus	1,18	1,87	2,95	4,02	5,89	6,76	4,81
EdEra	1,04	2,12	3,01	3,68	6,03	6,94	5,12
The Open University	1,24	1,97	2,76	4,17	5,84	6,63	5,26
Edx	1,11	2,07	3,24	4,31	6,24	6,80	5,08
Coursera	2,13	3,14	1,05	3,79	5,26	6,48	4,74
Intuit	2,41	1,27	3,15	4,02	4,87	6,81	4,86

The results analysis helped us to confirm the assumption about the necessity to consider one more criterion. The respondents recognized the greater importance of the criterion Responsiveness rather than the criteria Instructional Assessment and System Interactivity.

We offer to consider the evaluation results of the importance of usability subcategory in Table 4.

Table 4. Respondents' evaluation of the importance of usability subcategory.

Usability subcategories	Average estimate
1.1. Ease of navigation	0,91
1.2 Navigation support	0,72
1.3 Reference reliability	0,64
1.4 Understandability of sequence of actions	0,78
1.5 Ease of getting access	0,81
2.1. Ease of education	0,88
2.2 Reference predictability	0,42
2.3 Education without any initial preparations	0,56
2.4 Formulation clarity	0,71
2.5 Sufficient online assistance	0,65
3.1 Readability	0,57
3.2 Design aesthetics	0,74
3.3 Layout information content	0,63
3.4 Presentation structure	0,59
3.5 General course consistency	0,47
4.1 Information correctness	0,81
4.2 Information conformity	0,67
4.3 Information completeness	0,52
4.4 Ease of information understanding	0,87
4.5 Information timeliness	0,62
5.1 Evaluation tools efficiency	0,42
5.2 Ease of using evaluation tools	0,37
5.3 Reality of achieving learning objectives	0,93
5.4 Accessibility for material understanding	0,86
5.5 Feedback information content	0,72
6.1 Efficiency of communication tools	0,62
6.2 Implementation of communication between the tutor and student	0,71
6.3 Possibility of communication "student – student"	0,69
6.4 Interaction organization	0,53
6.5 Feedback speed	0,74
7.1. Layout flexibility	0,85
7.2. Image scaling	0,78
7.3. Media scaling	0,81
7.4. Menu flexibility	0,67
7.5. Navigation flexibility	0,91

According to the results, we can conclude that all the usability subcategories are important because any of them has a negative average rating.

4 Discussion

While researching the usability of educational platforms, scientists marked site usability as an important element of developing educational platforms.

Inductive Content Analysis Method helped to determine the direction of implementing usability criteria on the platform "Higher School Mathematics Teacher". We agree with the scientists A. Alshehri et al [6] that the most important criterion of usability design is Information Quality that describes the correspondence of the information in the system to learners' needs. We have also considered Y. Nilsen's and H. Loranger's point of view [18] who point out that the efficiency of any application work and its attractiveness for the user depend on search engine and navigation, downloading speed, menu design. In the authors' opinion the focus on the user, their needs and requests have to be principal. This idea is agreed with the conclusion provided by V. Hodakov and O. Boskin [19] in which they believe that the adaptive user interface is the main criterion of computer system attractiveness. Such interface reflects the capability of a simple software product or a complicated program technical complex to adapt to the user's needs, consider their psychophysical characteristics and abilities, dynamic change, support the consolidation of common actions to solve the given task.

The ranking results are presented in the diagram (Fig. 1).

While analyzing categories and subcategories we paid attention to the research by L. P. Dringus and M. S. Cohen [20] who defined 13 heuristic categories that influence the usability of the educational environment on the Internet. They include visibility, functionality, aesthetics, feedback and assistance, mistakes prevention, memory, course management, interactivity, flexibility, consistency, efficiency, mitigation, contraction, and accessibility. While researching the criteria of evaluating

the usability of the electronic education system, X. Fang and C. W. Holsapple [21] highlighted system navigation, performance system, visual design, information quality, instructive evaluation, and system interactivity. Following the results of their research, information quality is the most important criterion; navigation in the system of electronic education takes second place. Instructive evaluation and system interactivity are the least important design categories that influence the usability evaluation of the electronic education system. In order to consider the concept of the platform "Higher School Mathematics Teacher" [9], according to which we have to take into account the wish of different age audience of online courses, we followed the recommendations by L. Hasan [22] who studied the usability of educational websites from university students' perspective. The scientist defined that the content and navigation are the first and second desirable design categories that have to be considered during the usability evaluation of websites for educational programs while organization and architecture are the least important categories.

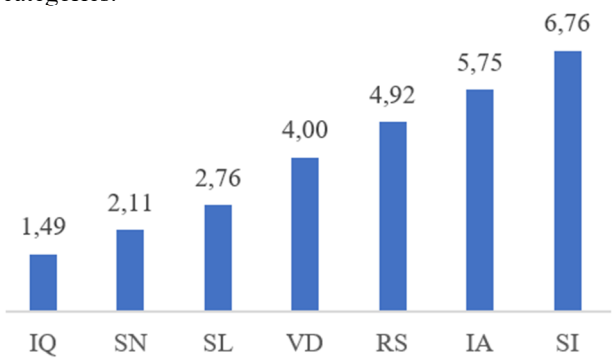

Fig. 1. The distribution of places categories from 1st to 7th depending on their impact on the usability of the platform (where 1 is the most important).

5 Conclusions

The actuality of researching the usability issue in educational software as a direction of developing distant education arises from the growth of the modern Internet education market. This implies particular requirements concerning the usability of online courses.

The Inductive Content Analysis Method helped us review the existing papers concerning the criterial basis of usability design. This method also helped to define the actual usability criteria of the educational platform as well as to provide an assumption about the necessity to consider the criterion driven by the presence and active usage of mobile devices.

In order to clarify the hypothesis, we developed a survey for teachers and students who are online course users. The analysis of survey results was held in two directions: to get descriptive statistics of online course users and study the relative importance of evaluating categories of educational platform usability. Such an approach to the survey allowed getting substantial information concerning the preferences of online course users that should be taken into consideration during its development.

Therefore, according to the research results, we found out that it is worthwhile to add the criterion Responsiveness that reflects the usability of mobile devices for online education. So, according to the results of researches and surveys, we offer the next order of usability criteria in descending order:

1) Information Quality (IQ),
2) System Navigation (SN),
3) System Learnability (SL),
4) Visual Design (VD),
5) Responsiveness (RS),
6) Instructional Assessment (IA),
7) System Interactivity (SI).

Further research will be aimed at the usability criteria analysis of the educational online platform "Higher School Mathematics Teacher".

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Green IT as a tool for design cloud-oriented sustainable learning environment of a higher education institution

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Abstract. The paper proposes the use of green IT as a tool for designing a cloud-oriented sustainable learning environment for a higher education institution. The article substantiates the expediency of designing such an environment as a prerequisite for the sustainable development of Ukraine. It is established that one of the goals of Ukraine's sustainable development for 2030 is to provide fair quality education and to promote lifelong learning opportunities for all. Green IT is a set of approaches related to sustainable computing and information technology. The work of foreign scientists was analyzed, which considered the issues of designing the learning environment using green computing. As a result, Cloud LMS has been established that cloud LMS is a type of green IT and can serve as a tool for designing a cloud-oriented sustainable learning environment of a higher education institution. A model of a cloud-oriented sustainable learning environment of a higher education institution using cloud LMS is proposed. The application of a cloud-oriented sustainable learning environment will provide such capabilities: keep electronic journals; use on-line services; conduct correspondence, assessment of knowledge on-line; and more. And all of the above is the key to a sustainable development of the learning environment.

1 Introduction

Sustainable human development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development of mankind and institutional changes agreed with each other that strengthen the current and future potential to meet human needs and aspirations [1, p. 7].

All these years, there has been ongoing work aimed at bringing to the world public an understanding of the nature and magnitude of the danger, coordinating the activities of international organizations, governments, non-governmental organizations, scientists in the search and implementation of effective measures to reduce the level of global threats to humanity.

To create conditions for sustainable development for the country, it is necessary to focus on the implementation of such important components as:
- economical – represents the economical use of all types of resources aimed at reducing pressure on natural ecosystems;
- ecological – a series of actions that lead to the restoration of the original state of the environment to a level that does not harm either human health or natural ecosystems and helps to maximize improvement;
- social – an integral part, which provides for the improvement of the quality of life of a person, because the person acts as the main cause of changes occurring in society.

According to the 2030 Sustainable Development Strategy of Ukraine, one of the goals of sustainable development is to provide equitable quality education and to promote lifelong learning opportunities for all, which envisages ensuring lifelong access to quality vocational and higher education for the whole population, significantly increase the number of young and adult people who have the socially necessary skills, including vocational and technical skills for employment, decent work, and entrepreneurial employment what activity [2].

At the same time, green information technology is a "set of approaches related to environmentally friendly computing and information technology. It is the science and practice of designing, manufacturing, using and utilizing computers, servers and their subsystems, such as monitors, printers, devices storage of data, networks and communication systems – effectively and with minimal or zero environmental impact" [3].

2 Literature review

Sustainable computing in recent years increasingly involved scientists from around the world [4-17]. In particular, V. Kharchenko and O. Illiashenko offers concepts of green IT engineering: taxonomy, principles, and implementation [6], Y. Kondratenko, O. Korobko,

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O. Kozlov views PLC-oriented systems for data acquisition and supervisory control of environment-friendly energy-saving technologies [7], N. Boroujerdi and S. Nazem considering cloud computing as changing cogitation about computing [8], V. Kharchenko, Y. Kondratenko, J. Kacprzyk offers concepts, models, complex systems architectures, studies in systems, decision, and control of Green IT engineering [9], Y. Kondratenko, V. Korobko, O. Korobko, G. Kondratenko, O. Kozlov considering Green IT approach to design and optimization of thermoacoustic waste heat utilization plant-based on soft computing [10].

Other scientists – J. Drozd, A. Drozd, S. Antoshchuk view resource-oriented approach of Green IT engineering [11], V. Hahanov, E. Litvinova, S. Chumachenko offers green cyber-physical computing as sustainable development model [12], N. Bardis view secure, green implementation of modular arithmetic operations for IoT and cloud applications [13], and N. Doukas considering technologies for Greener Internet of Things systems [14].

K. Palanivel and S. Kuppuswami in their study proposed a cloud-oriented green computing architecture for e-learning applications: COGALA [15]. This is due to the fact that the rapid development of cloud technologies in the future implies a lack of high-speed cloud-oriented architectures for educational institutions [15]. They also offer their models of cloud-oriented e-learning architecture (see Figure 1) and cloud-oriented green computing architecture for e-learning (see Figure 2) [15].

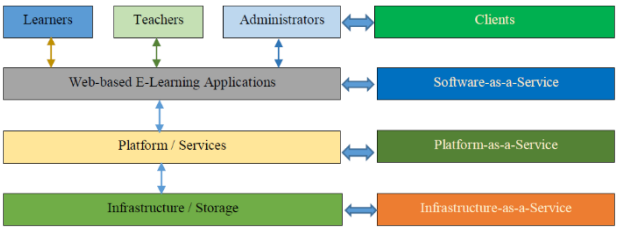

Fig. 1. Cloud-oriented e-learning architecture model (K. Palaniwell and S. Kupuswami).

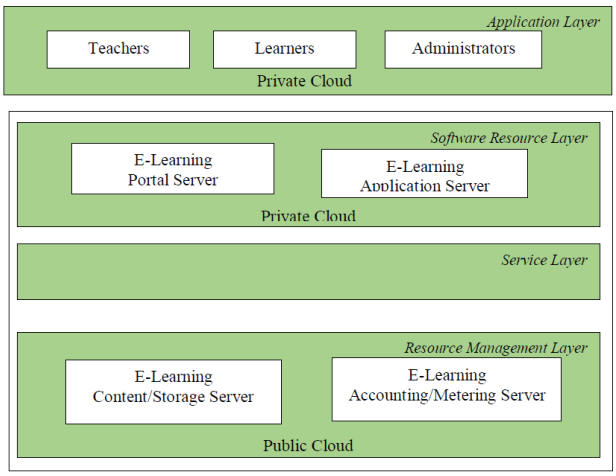

Fig. 2. Cloud-oriented green computing architecture model for e-learning (K. Palanivel and S. Kupuswami).

Figure 1 presents the architecture of an e-learning system based on a cloud-oriented architecture, according to which the model is divided into three levels, including infrastructure, platforms, and applications. At the infrastructure level, training resources from the traditional system are transferred to the cloud database instead of the usual database. The platform level involves the use of a new e-learning system based on CMS (Content Management System) and LMS (Learning Management System). These components are important in the model because they are designed to mediate between a cloud-oriented database and native applications. Finally, the application layer was designed to interact with the client (student, teacher, administrator) [15].

K. Palanivel and S. Kuppuswami also propose a model of a cloud-oriented green computing architecture for e-learning (see Fig. 2) [15]. It is divided into four levels: the public cloud resource management layer and containing the e-learning content/storage server on the e-learning accounting/metering server; level of service; the level of software resources hosted in a private cloud consisting of a portal server and an e-learning application server; application level, which is also hosted in a private cloud (at this level, users are teachers, students, administrators) [15].

3 Results

However, the problem of creating a cloud-oriented sustainable education environment for higher education institutions is nowadays needed to be addressed. That is why the structure and functioning of the cloud-oriented sustainable learning environment higher education institution that underlies the design of such an environment remain unexplored.

According to the V. Yu. Bykov and V. H. Kremen, to design the learning environment means to theoretically investigate the essential target and content-technological (methodical) aspects of the educational process which should be carried out in the learning environment, and on this basis to describe the necessary for this purpose the structure and structure of the learning environment (its statics and dynamics, including to predict and take into account the development of the structure of the learning environment, the influence and peculiarities of the relationship of the learning environment components with other elements of the environment, with the elements of the environment) in accordance with the dynamics of the development of its goals creation and use, and limitations of psychological and educational, scientific and resource nature [16, p. 7].

Summarizing the above interpretation, it can be argued that the theoretical study of the learning environment is to create a model that will provide an idea of the learning environment in which the cooperation and communication of all participants in the educational process.

Specialized platforms, such as LMS, are constantly being created at the higher education institution to address the challenge of deploying higher education institution education and training systems online and in designing a cloud-oriented learning environment. They are used to develop, manage, and distribute educational online sharing materials. The materials are placed in a learning

environment with the definition of the sequence of their study. LMS is comprised of a variety of individual tasks, small-group projects, and learning elements for all students, both content-oriented and communicative.

There are several training management systems that allow learning using the Internet. Thus, the learning process can be done in real-time by organizing online lectures and seminars.

LMS in the form of use is conventionally divided into two types [17, p. 117]:

1. **LMS as software** that is intended for installation on your own higher education institution servers. The use of LMS of this type implies receiving an appropriate service from an IaaS cloud provider. The operation of such LMS requires the availability of appropriate personnel and software.
2. **LMS as a cloud platform** created by a provider used by users to manage the educational process. The use of LMS of this type involves obtaining an appropriate service from an higher education institution using a SaaS cloud service model. Due to this, all the basic functions of maintenance and technical support are assigned to a specific provider.

As a result of our research, consider that cloud LMS is a type of Green IT.

After analyzing the main scientific papers on the subject, a generalization and model of a cloud-oriented sustainable learning environment of a higher education institution in the following form were summarized (see Fig. 3).

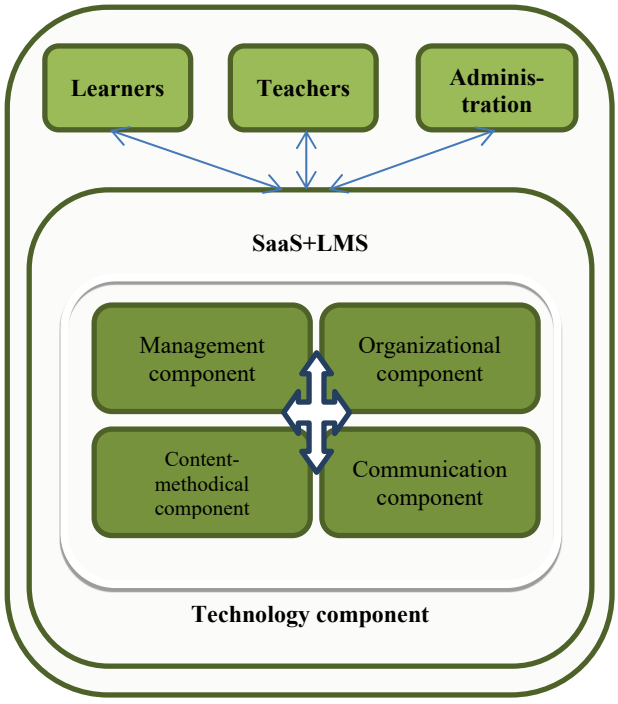

Fig. 3. Model of a cloud-oriented sustainable learning environment of a higher education institution

Since learning environment "is an artificially constructed system, structure, and components which create the conditions necessary to achieve the objectives of the educational process ... and learning environment structure determines its internal organization, relationship and interdependence between its elements" [18, p. 3], then the proposed model (see Fig. 3) is oriented towards the achievement of the learning objectives, which are reflected in the industry standards of higher education through all structural constituents of the cloud-oriented sustainable learning environment of the higher education institution.

To achieve the learning objectives, a cloud-oriented sustainable learning environment in a higher education institution should fulfill the following functions:

- *management* – management of the educational process of preparation of future professionals;
- *organizational* – organizing the actual learning process through the distribution of access rights and the distribution of communities of entities;
- *educational* – submission of educational materials, as well as practical and laboratory work;
- *advisory* – providing on-line consultations to students and groups of students;
- *communication* – the presence of subject-subject interaction, as well as the possibility of communication between the subjects, which is also the implementation of a feedback mechanism;
- *controlling* – the availability of an electronic journal and the ability to evaluate works online;
- *developmental* – development of students' information and communication competencies;
- *systematic* – systematization of materials.

These functions are possible in the presence of the following structural components of a cloud-oriented sustainable learning environment of a higher education institution.

The technological component is implemented through the use of a cloud-oriented learning management system and combines managerial, organizational, content and methodical and communication components that are interconnected with each other.

A cloud-oriented learning management system will be understood to mean a system that facilitates group collaboration between faculty and students, the development, management, and dissemination of educational materials with the sharing of the educational process through cloud technology.

Consider in detail each of its components.

The management component provides for the use of cloud-oriented learning management tools and cloud-oriented learning performance assessment tools in the educational process of a higher education institution. Also within this component should be defined as the disciplines provided by the curriculum of the relevant specialty.

The cloud-oriented sustainable learning environment of the institution of higher education provides great opportunities for control of students' educational activities: laboratory work, testing, independent work, joint projects, control works, etc.

Organizational component.

The successful functioning of a cloud-oriented sustainable learning environment in a higher education institution is possible provided that a logical distribution of user access rights is made. The following users are

highlighted: admin; lecturer (including representatives of higher education institution administration); students.

Note that each user group has limited access rights to its own cloud-oriented sustainable learning environment of a higher education institution. Students may have the opportunity to read or edit a variety of teaching and teaching materials.

Each teacher in the cloud-oriented sustainable learning environment of the higher education institution is provided with his own cloud-oriented office, where he can store all the necessary materials for successful and high-quality classes: educational and work programs of disciplines, textbooks, manuals, lectures, laboratory materials, exam requirements, coursework and diploma instruction, etc.

With such advanced functionality, teachers can provide access to all the necessary materials, allowing students to complete: joint projects, independent work, research work, etc.

The following types of documents should be developed, structured and made available to faculty members in a cloud-oriented sustainable learning environment for higher education institutions:

− regulatory documents both at the national level and at the university level;

− curricula for the preparation of future professionals;

− methodical recommendations on filling of educational-methodical complexes of disciplines.

When designing this component, it is necessary to take into account all the necessary components: the schedule of classes, terms of delivery of work, the plan of work of the department, faculty, announcements, discussions, contacts, etc. And given the specifics of cloud technologies, it is advisable that a cloud-oriented sustainable learning environment in a higher education institution also has internal communication tools (a kind of its social network), a forum (to engage all subjects in the educational process). Also positive is the creation of photo albums of groups, departments, which would contain materials of all events taking place in higher education institution.

In order to control the success and quality activities of teachers in the educational process in the cloud-oriented sustainable learning environment of a higher education institution, an administration should be present. The administration controls: the conformity of the available subjects in the cloud-oriented sustainable learning environment of a higher education institution to the curricula for the training of specialists in the relevant specialty, the conformity of the educational materials placed in such environment to the curricula of all disciplines.

This provides the opportunity: keep electronic journals; testing, and assessment of knowledge on-line; and more.

Content-methodical component.

Learning objectives affect the content of the training, which in combination influences the choice of tools, methods, and forms of organization of education in higher education.

The content of a cloud-oriented sustainable learning environment of a higher education institution is in line with all concepts of education, industry standards of higher education, curricula for the training of relevant specialists, educational and work programs of the disciplines envisaged for mastering.

In this case, each component of the methodological system is divided into traditional and cloud-oriented components. It should be noted that cloud-oriented learning tools complement the traditional higher education educational process.

The use of cloud-oriented learning tools facilitates the identification of traditional and cloud-oriented methods and forms of the learning organization. By cloud-oriented methods and forms of training organization, we will understand such methods and forms that are implemented in the educational process with the use of cloud ICT infrastructure.

Proper selection of modern methods, forms and tools of teaching (cloud-oriented and traditional) in accordance with the goals of a certain discipline promotes the development of cognitive abilities of students, the development of creative and logical thinking, the formation of skills to use the acquired knowledge in practice, the formation of necessary professional competences, including information and communication competence as a component of professional competence of future specialists for further creative activity.

This provides the opportunity: use on-line services for the educational process; possibility of distance learning, library of books, textbooks, media files; file repositories and more.

Communication component.

Communicating between subjects of training activities implemented directly with each other and through cloud-oriented communications in a cloud-oriented sustainable learning environment of a higher education institution.

Important in the communication component is the selection of modes of communication. According to V. Yu. Bykov, they are synchronous and asynchronous [19, p. 323]. The synchronous mode of communication implies simultaneous interaction of the subjects of learning at one time, and the asynchronous one assumes independence of the interaction time of the subjects of the educational process.

The successful and quality functioning cloud-oriented sustainable learning environment of a higher education institution should be provided both modes of communication.

Considering the interaction of the participants in the learning process in a cloud-oriented sustainable learning environment of a higher education institution, it is first of all necessary to determine the subjects of interaction. In our case, the subjects of interaction are the student, the teacher, and the scientific supervisor.

It should be noted at the outset that the scientific advisor is distinguished by a separate entity because the curricula of higher education institutions include such types of work as the writing of coursework and diploma projects (papers), in which the scientific supervisor plays a leading role.

The subjects of interaction define the links of interaction in the cloud-oriented sustainable learning environment of a higher education institution, which

should include: student-student, student-teacher, teacher-student-student, student-scientific supervisor. It should be noted that the interaction of teacher-student-student is one of the defining elements in the educational process of a higher education institution. After all, it depends on her interpersonal relationships not only students but also students with the teacher.

Different levels of interaction covering the various types and forms of interaction. In particular, the following types of interaction are highlighted: individual activity, group interaction, subgroup interaction, and couples interaction.

In a cloud-oriented sustainable learning environment of a higher education institution, students independently perform tasks (individual work), perform joint projects, discuss problems (interaction in pairs, subgroups), use the process of learning (interaction in pairs, subgroups, groups), communicate with each other (interaction in groups).

The main forms of interaction between the subjects of the educational process in such an environment include: information, consultation, discussion, collaboration, webinar, learning materials, assessment of the knowledge, and communication in groups. Forms and types of interaction are closely related.

Teacher in a cloud-oriented sustainable learning environment in a higher education institution can inform students about a particular event, tools of adding news and calendar events; subgroups or groups of students. In particular, the supervisor can inform students of the problem group about the extraordinary meeting, etc.

Through consultations, students can get answers to questions that interest them, whether from a teacher in a particular subject or from a research supervisor for writing an article or coursework (diploma) project.

Another important form of interaction is the discussion, where students and the teacher (supervisor) are equal subjects of learning, resulting in the formation of their own opinion and the opportunity to defend it in a subgroup, group or team. This is also closely related to the form of group communication. Students can communicate through correspondence, chats.

In the process of performing laboratory work students often need the help of classmates, teachers. In this case, cooperation is a profitable solution. In cooperation, students develop such personal qualities as the ability to work in a team, sociability, etc.

To conduct online seminars for problem groups in such an environment is used webinar. This is quite a useful opportunity during the holidays and quarantine.

For successful mastering of the material, there is an opportunity to receive educational materials (lectures, theoretical information, literature, etc.). It is also a form of educational interaction, without which the learning process as a whole is not possible.

Evaluation of knowledge – is a form of interaction between actors, which is not possible without learning. That is why in a cloud-oriented sustainable learning environment of a higher education institution, this form of interaction is envisaged for further e-journaling and rating of a specific subject.

It should be noted that the main tools of communication are: dialogue, brainstorming, discussion, debate, debate, and their application transforms the educational process into mutual learning, where the student and the teacher are equal subjects of learning.

4 Conclusions

The designed cloud-oriented sustainable learning environment of a higher education institution should optimally address the challenges facing higher education institutions:

1. Planning of the educational process on different curricula and forms of study (full-time, part-time).
2. Organization of the educational process.
3. Organization of research work.
4. Submission of teaching materials.
5. Ensuring interaction between all participants of the educational process in the higher education institution.
6. Provision of information for teachers and students in various fields.
7. Ensuring the distribution of user access rights.
8. Organization of communities.
9. Ensuring that all necessary materials are shared.
10. Providing management of the educational process of preparation of future professionals.

Obviously, the main benefits of this environment for higher education institutions include: saving money on purchasing licensed software and not just software (everyone can use Office technology online); reducing the need for specially equipped premises; carrying out various types of educational work, control and assessment of knowledge online; saving computer memory (disk space); antivirus security of the educational environment; openness of the learning environment for teachers and students.

The design and application of a cloud-oriented sustainable learning environment with cloud LMS will provide such capabilities: keep electronic journals; use on-line services for the educational process; conduct correspondence, testing, and assessment of knowledge on-line; possibility of distance learning, library of books, manuals, textbooks, media files; file repositories; conference video and more. And all of the above is the key to a sustainable development of the learning environment.

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Cloud-oriented environment for flipped learning of the future IT specialists

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Abstract. The article deals with the creation and use of the cloud-oriented environment for flipped learning in the process of training future IT specialists in higher education institutions. It describes the organization of the students' project work based on flipped learning using the services and resources of the cloud-oriented educational environment. It identified the following components of such an environment: resources of the university's training portal, mass open online courses, profession-oriented software applications and project management services. The present research offers the model of flipped learning for the implementation of the cross-disciplinary project for the formation of professional and personal competences of future IT specialists. It provides the results of an experimental study of the effectiveness of the proposed cloud-oriented environment application in the implementation of the cross-disciplinary project from the perspective of students and teachers by three criteria: functionality for professional activity, project management and flipped learning.

1 Introduction

Sustainable development depends on innovation and the introduction of ICT in various sectors of the economy and livelihoods. That is why providing inclusive and equitable quality education, promoting lifelong learning for all, is one of the global goals of sustainable development. The issue of training quality IT professionals is especially relevant in the context of achieving sustainable development goals, as modern innovation is based on the widespread use of IT. Higher education institutions are constantly confronted with the educational and technological challenges involved in preparing future IT specialists. Teachers are faced with the task of finding new approaches to solving the problem of improving the quality of the educational process, developing students' professional and personal skills. Moreover, employers' expectations of professional qualification requirements must be met. In addition to professional competencies, teamwork, problem-solving and communication skills, so-called soft skills, should be addressed in the future IT specialists.

We are looking at flipped learning as a way of creating a learning ecosystem, we realise how effective it is. Flipped classrooms connect people and provide them with a variety of content and technology. This increases the engagement of the learners as there is activity-based, practical learning in classroom time. Flipped learning also boosts healthy interaction between members, in a mutually beneficial manner, which is the essential function of an ecosystem. Blended learning, interaction between members and informal learning are other characteristics of a flipped classroom that take you closer to developing a learning ecosystem.

Case studies are emerging, in ever greater numbers, which document measurable improvements in student and teacher motivation, increased attendance in class, and better grades, as a result of using the flipped approach [1, 2, 3].

Innovative approaches in higher education are shifting away from teacher centered instruction to student-centered learning [4].

Technological challenges and the need to develop personal performance and self-education competences of future IT specialists pose the challenge of designing an effective educational environment. The purpose of this article is to design a cloud-oriented environment for flipped learning in the process of training the future IT specialists, as well as to study the performance indicators of such an environment.

2 Theoretical background

There are two common characteristics which encapsulate a flipped classroom: (a) an easily adaptable learning environment that facilitates active learning and allows students to develop different skills and competencies [5, 6, 7, 8]; (b) a student-centred learning culture [2, 9] and others.

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According to the Flipped Learning Network the flipped classroom approach has four pillars. In order for teachers to achieve this approach, they have to take these four elements into consideration:
- Flipped learning requires flexible environments.
- Flipped learning requires a shift in learning culture.
- Flipped learning requires intentional content.
- Flipped learning requires professional educators.

The concept of flipped learning is to provide to student's lectures in a video format and other supportive materials to review as their homework, get the maximum of it, and then, use the next class time for in-class activities and problem-solving exercises. The flipped classroom serves as a platform to achieve a collaborative and organic learning environment. To meet the challenges and complexities of the 21st-century workplace environment, there has been a shift and adoption of an organic learning environment in the business community. Similarly, universities and accreditation bodies in business schools are moving towards developing competency-based curricula where learners foster lifelong learning skills through a process of self-directed learning [10].

Flipped learning approaches have students use technology to access the lecture and other instructional resources outside the classroom in order to engage them in active learning during in-class time [11].

O. Kuzminska, N. Morze, E. Smyrnova-Trybulska describes scenarios and collaboration tools for students' practical activity, provides examples of learning objects representing resources for independent study and research, and criteria for assessing the effectiveness of the proposed model of flipped learning [6].

The active learning techniques integrate the student centered learning methods such as cooperative learning, problem-based learning, project based learning and peer assisted learning. These learning approaches mean that students work in groups in order to develop and reach their learning goals [4].

One of the aims of the flipped learning technology is the transition of the educational process organization from passive student learning to the active one, in which future specialists participate in collaborative work, carry out team projects, discuss and solve practical problems in the classroom, applying the theoretical knowledge they have acquired prior to the classroom lessons. By providing students with basic theoretical knowledge prior to the class, the teacher becomes a facilitator, thus enabling students to deepen their knowledge and practical skills during the class and independently manage their own educational process.

The scheme of the educational process organization under the flipped learning technology of future specialists in information technologies is presented in Fig. 1.

Prior to the classes, students need to acquire basic theoretical knowledge in each academic subject using the resources of the e-learning course (ELC), further deepen the acquired knowledge independently by studying the various MOOCs recommended by teachers. During the classes, students plan joint activities, work on the project as a team, performing practice-based tasks. In the classroom, students consult the teacher on the problematic issues. After classes, the student teams performed tasks assigned to each participant within the project and addressed controversial issues if they arouse among the team members regarding the project tasks.

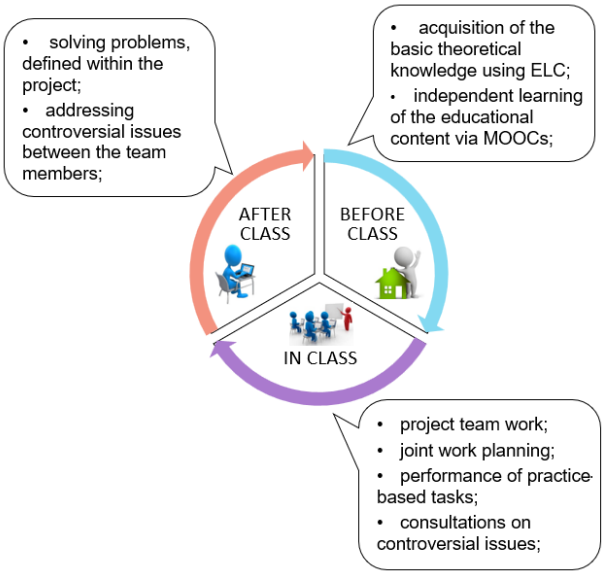

Fig. 1. The scheme of the educational process organization under the flipped learning technology.

The use of modern information technologies further enriches the flipped learning process and foster the skills needed by future IT specialists. At the World Economic Forum in 2019, it was determined that it is important to pay attention to the ways and forms of the educational process organization, out of which they single out the study of information technologies with an emphasis on teamwork and creativity, learning through games that develop critical thinking, support of students' initiative outside the educational programs.

A cloud-based environment for organizing the learning process through the technology of flipped learning should provide e-support for the activities of students and teachers at the stages "before class", "in class", "after class". The essence of the notion and the possibility of using a learning environment in their studies are considered by the following scientists: O. Saad, M. Rana [12], A. Salam, N. Sardar [13], M. Shyshkina [14, 15], Y. Nosenko, M. Shyshkina, V. Oleksiuk [16], M. Popel [17] et al.

O. Spirin, V. Oleksiuk, N. Balyk, S. Lytvynova, and S. Sydorenko describe a cloud environment for the study of the "Computer Networks" academic discipline in their article [18], which was deployed at the Faculty of Physics and Mathematics of Ternopil Volodymyr Hnatyuk National Pedagogical University and investigate the effectiveness of blended learning in such an environment.

Supported by the information and communication technologies, teachers have many options for improving the effectiveness of teaching, in particular the organization of teamwork projects in the process of training future IT specialists.

The cloud-oriented environment was designed at the National University of Life and Environmental Sciences (NULES) of Ukraine for training the future IT specialists

under the flipped learning technology (Fig. 2). Selection criteria for cloud services and resources that will be appropriate in the process of training future IT professionals are analysed in articles [19]. The university's cloud-oriented environment provides students, who major in IT with a variety of types of resources and services that make it possible to use:

- prior to classes within the framework of independent work with e-resources: e-learning courses (ELC) in accordance with the curriculum for training specialists using the LMS Moodle platform; Khan Academy; online courses from Microsoft and Cisco leading technology companies, respectively, Microsoft Imagine Academy, Cisco Networking Academy; Massive Open Online courses (MOOC), such as Coursera, Udemy, Prometheus, edX, Khan Academy and others;
- in the classroom: professionally-oriented software and cloud services, namely: Microsoft Office 365; Visual Studio; draw.io; services for collective IT development (GitHub, Bitbucked, DeployBot, Phabricator, BeanStalk); Miro;
- for the cooperation outside the university, services to manage collective projects such as: Microsoft Teams, Jira, Trello, Asana, YouTrack.

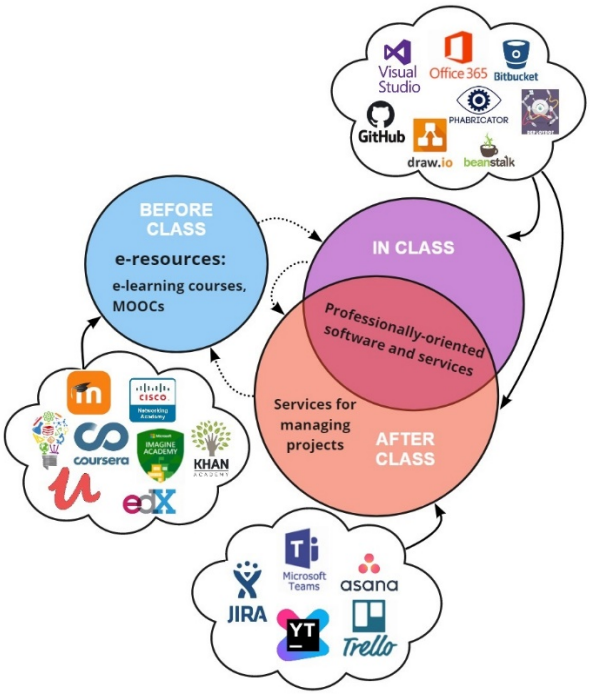

Fig. 2. Components of the cloud-oriented environment for flipped learning.

The design of a cloud-oriented environment for the implementation of the cross-disciplinary project enables teachers to choose the means available to complete the project's tasks, integrate the necessary services and resources into the created environment, and provide communication between the educators, who teach the project disciplines and the teams of students; students have the opportunity to effectively plan project implementation steps, distribute tasks among team members and monitor their implementation, organize teamwork to create the end product of the project.

3 Presentation of research

The cross-disciplinary project provided for a combination of the tasks of the three disciplines, namely: System Analysis, Web Technologies and Web Design, Economics and Business. This project was implemented under flipped learning technology using the designed cloud-based university environment. To ensure the work of students on the implementation of this project at the stage of organization, a schedule for the implementation of the project was developed and a project day was allocated, during which the students performed the task.

The students were offered to implement the cross-disciplinary project on the topic of "Web-oriented system for the IT industry", with the purpose of carrying out systematic analysis, developing a web-oriented system and evaluating the investment attractiveness of the developed system. The content of the project was to develop a project for starting their own IT-business, namely: conducting an analysis of the IT services market; carrying out structural, functional and object-oriented analysis of the domain; designing the database and system functionality; developing a web-based system for the IT company; creating a business plan for the company and accordingly calculating the payback of the project as well as strategizing the company's development.

We distinguish the following 8 stages of such a collaborative project implementation under the flipped learning technology: setting a task and processing theoretical material (1); structuring the task and subdividing it into specific tasks (2); role distribution, definition of terms and responsibilities (3); performance of basic tasks (4); joint work of the task team (5); assessment of the quality of the task (6); drawing up a report on the work performed (7); presentation of results (8).

The teamwork was subdivided into 3 parts, according to the tasks of each academic discipline that were part of the cross-disciplinary project. In the course of completing the tasks in the "System Analysis" academic discipline, the students had to conduct an analysis of the IT services market, to choose the profile of the future company, to develop the functionality of the future business, to carry out structural-and-functional and object-oriented analysis, to design information support and to describe the specification of management processes. In the course of "Web Design and Web Technologies" academic disciplines, the students developed the website of the future company and integrated it into the information management system of the company. The tasks in the "Economics and Business" academic discipline required students to analyze the necessary tools to start their own business, to develop a business plan for the future company, to formulate a strategy for its further development, to calculate the basic income and expenditure, as well as to evaluate its economic efficiency and investment attractiveness.

Prior to the commencement of training (before class): instructions were developed for each task of the project beforehand, and necessary training materials were placed in electronic training courses (ELCs) for each academic discipline. The teaching materials at ELCs were designed

according to the students' learning styles. Often the same material was offered in different formats according to the research provided in [20]. Thus, the students studied basic theoretical materials in the ELC of the corresponding academic disciplines, got acquainted with the project objectives, registered and selected MOOCs for the independent study of the required material in accordance with their learning style. An in-depth study of the theoretical material, required for students to complete the assignments, took place in lectures alternately in each academic discipline as per schedule. The students studied the selected professionally oriented software and project management services offered by the teachers for each stage of the cross-disciplinary project.

In class: all the students were required to participate weekly in interactive lectures and laboratory work. During such classes, students were asked to develop a project based on the tasks of three identified academic disciplines of the cross-disciplinary project. The first session involved getting acquainted with the subject and tasks of the project in detail in each academic discipline. The students were divided into teams of 4 people, then within the team they were assigned roles and areas of responsibility of each team member; further the team members defined the terms of implementation and appointed those responsible for each project task. The task of the students was to understand the problem, to evaluate the complexity of the works, to find options for their solution, to divide the received tasks into separate tasks, to apply the theoretical and practical knowledge acquired before the beginning of classes to solve the project's tasks. In class the students were advised by the teacher on the progress of the course; they acquired basic skills in performing specific tasks via professionally oriented software and services of the university cloud-oriented environment.

After class: team members jointly performed project tasks in each academic discipline, collaborated using project management and IT-team services. In the course of the project, the students evaluated the tasks completed personally as well as those completed by other team members. If necessary, they refined the tasks to the appropriate professional level, created reports in the form of a presentation, which reflected the results of the team at all stages of the project. In the end, each team presented the results of their project, and teachers and participants of other teams evaluated the readiness for the implementation.

Fig. 3 shows a diagram of one of the cycles of fulfilling the tasks of a cross-disciplinary project under the flipped learning technology using the cloud-oriented university environment.

Table 1 defines in more detail the types of activities in the process of the implementation of each stage of the project, during which the students develop professional, integrated, self-educational competences and soft skills, for each of the above stages of the cross-disciplinary project using a cloud-oriented environment.

Thus, the implementation of such cross-disciplinary project tasks involved activities at certain stages, which resulted in the development of professional, integrated, self-educational competences, as well as communication, interpersonal, leadership, teamwork and time management skills, the so-called “soft skills”.

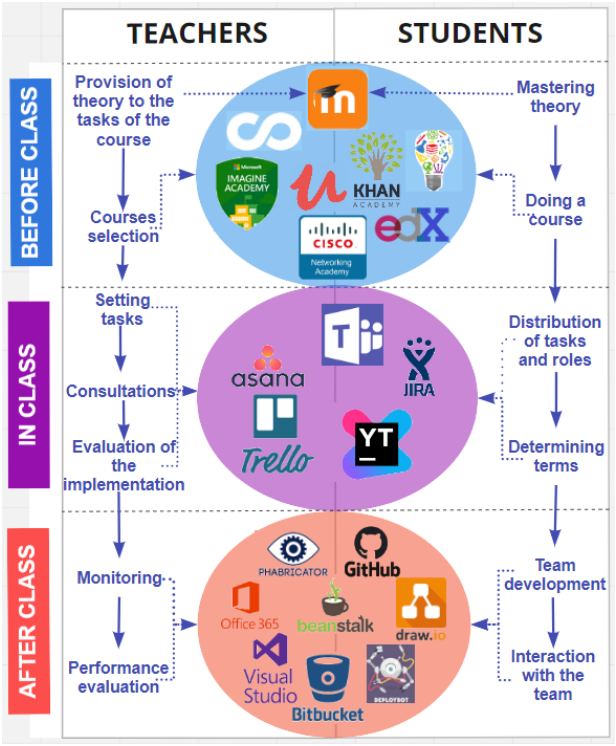

Fig. 3. The diagram of one cycle of the cross-disciplinary project under the flipped learning technology using the cloud-oriented university environment.

Table 1. Organization of the cross-disciplinary project under the flipped learning technology using the cloud-oriented environment.

Contents of the stage	Activity	Tools	Competence
Before class			
Setting tasks and mastering of the theoretical material	getting acquainted with the aim and tasks of the project; studying the theoretical material in ELC; registration and selection of MOOC; doing online courses	LMS Moodle; Cisco Academy; Prometheus; Coursera; Microsoft Imagine Academy; Udemy; Khan Academy	self-educational; professional; ability to search, process and analyze information from various sources
In class			
Structuring the material and dividing it into specific tasks	evaluation of the task complexity; search for solutions to the problem; division of the task into separate tasks	Microsoft Teams; Jira; Trello; Asana; YouTrack	ability to work in a team; knowledge and understanding of the subject area; ability to make decisions

Contents of the stage	Activity	Tools	Competence
Allocating roles, appointing people in charge, setting the date	allocation of roles and areas of responsibility of each team member; appointment of those responsible for each task; determining the timing of each task	Microsoft Teams; Jira; Trello; Asana; YouTrack	ability to work in a team; ability to make decisions
Performing basic tasks	solving practical tasks according to the aim of the task performance; consultation with the teacher on problematic issues	GitHub; Bitbucked; DeployBot; Phabricator; BeanStalk; professionally-oriented software and services	professional; integral; the ability to apply knowledge in practical situations
After class			
Team work on task completion	step-by-step implementation of project tasks in each academic discipline (domain analysis, site development, project cost-performance calculation)	GitHub; Bitbucked; DeployBot; Phabricator; BeanStalk; professionally-oriented software and services	professional; integral; the ability to apply knowledge in practical situations
Evaluation of the quality of the task performed	evaluation of independently completed tasks; evaluation of tasks performed by other team members; refinement of tasks	GitHub; Bitbucked; DeployBot; Phabricator; BeanStalk; professionally-oriented software and services	ability to be critical and self-critical; the ability to evaluate and ensure the quality of work performed
Report generating on the work performed	generating a team work report on the project	PowerPoint Online; Sway	the ability to visualize, formulate, solve problematic situations, making the right decisions, taking into account available information
Presentation of results	report placement; evaluation	Miro	the ability to present the project to investors or your own team

4 Results of research

The timeframe of the study is 3 years. The pedagogical experiment involved students of the 3rd year of Computer Science specialty at the Faculty of Information Technologies of NULES of Ukraine. We conducted an expert evaluation using a survey among students of NULES of Ukraine.

To understand the attitude of students to the cloud-oriented environment of the university, we have defined 3 criteria for evaluating them from the standpoint of functionality of the cloud-oriented environment:

- to perform professional tasks;
- to implement the flipped learning technology;
- to manage project implementation.

Indicators under the first criterion include: accessibility (ability to work from any device); reliability (high-quality functioning of the cloud-oriented environment); flexibility (designed and used in line with learning objectives); expediency (need for use to solve problems); convenience (clarity and ease of use); support for processes (communication, collaboration, cooperation, planning and control); teamwork (the ability to organize teamwork, create team projects); integrity (ensuring a continuous educational process); integration with other cloud services; support of various programming technologies; the ability to access open code software.

Indicators under the second criterion are the following: availability of training resources in a cloud-oriented environment; completeness of educational material for students to acquire theoretical knowledge independently; completeness of training material necessary for practical tasks; convenience for independent preparation for the class; convenience of interaction of team members in practical activity; convenience for self-control; convenience for checking the level of acquired knowledge.

Indicators under the third criterion are the following: ease of team work organization; convenience in planning the work on a collaborative project; ease of roles and areas of responsibility allocation for each team member; the convenience of controlling the timing of each task; convenience of communication among the team members; ease of interaction of team members during team development; ease of checking completed tasks; ease of managing software versions.

In order to determine the effectiveness of the cloud-oriented environment under the above-mentioned categories and evaluation indicators, 34 students and 8 teachers were interviewed after conducting a cross-disciplinary project based on flipped learning technology using the cloud-oriented environment. A questionnaire was developed in which students and teachers were asked to rate the importance of each of the previously identified environmental indicators by three categories separately (Table 2-4).

Experts evaluated the degree of significance of parameters by assigning them a ranking number. The highest rated indicator was assigned a rank of 1.

To evaluate the consistency of experts' opinions, we used the concordance coefficient, which was calculated by the formula:

$$W = \frac{12S}{m^2(n^3-n)} \quad (1)$$

$$S = (\sum x_{ij} - \frac{\sum\sum x_{ij}}{n})^2 \quad (2)$$

where n – is the number of factors, m – is the number of experts.

The weights of the considered parameters were calculated on the basis of the sums obtained.

Table 2. Evaluation of the results for determining the performance of a cloud-oriented environment.

Indicators	Teaching staff			Students		
	Rank sum	S	Weight	Rank sum	S	Weight
accessibility (ability to work from any device)	80	1024	0.02	164	1600	0.11
reliability (high-quality functioning of the cloud-oriented environment)	52	16	0.08	297	8649	0.04
flexibility (designed and used in line with learning objectives)	10	1444	0.18	237	1089	0.07
expediency (need for use to solve problems)	54	36	0.08	311	11449	0.03
convenience (clarity and ease of use)	52	16	0.08	264	3600	0.06
support for processes (communication, collaboration, cooperation, planning and control)	20	784	0.15	47	24649	0.17
teamwork (the ability to organize teamwork, create team projects)	34	196	0.12	204	0	0.09
integrity (ensuring a continuous educational process)	41	49	0.11	329	15625	0.02
integration with other cloud services	36	144	0.12	137	4489	0.13
support of various programming technologies	67	361	0.05	73	17161	0.16
the ability to access open code software	82	1156	0.01	181	529	0.1
Total	528	5226	1	2244	88840	1
Concordance coefficient	0.742			0.693		
Calculated χ^2	59.36			235.62		
Table χ^2 (k=10, α=0,05)	18.309			18.309		

When evaluating the performance of a cloud-oriented environment, the teaching staff found out that flexibility, support for the process, teamwork, and integration with other cloud services were the most important indicators. The concordance coefficient was 0.742, which indicates a high level of agreement of experts' opinions.

The significance of the concordance coefficient was determined by the Pearson correlation criterion: $\chi^2 = m(n-1)W$. Comparing the calculations of χ^2 (59.36) with table values (18.309) when number of degrees of freedom is K=n–1=11-1=10 with the given significance value of α=0.05, we may conclude that W=0.742 – is not a random value, and therefore the obtained values are statistically significant.

In evaluating the performance of a cloud-oriented environment, students identified the following most important indicators: support for the process, support of various programming technologies, integration with other cloud services, and accessibility. The concordance coefficient was 0.693, which indicates the average degree of agreement of experts' opinions.

Table 3. Evaluation of the results of determining the effectiveness of the cloud-oriented environment for the project activity.

Indicators	Teaching staff			Students		
	Rank sum	S	Weight	Rank sum	S	Weight
ease of teamwork organization	11	625	0.24	56	9409	0.23
convenience in planning the work on a collaborative project	22	196	0.19	162	81	0.12
ease of roles and areas of responsibility allocation for each team member	51	225	0.06	243	8100	0.03
convenience of controlling the timing of each task	54	324	0.04	185	1024	0.09
convenience of communication among the team members	61	625	0.01	156	9	0.12
ease of interaction of team members during team development	15	441	0.22	68	7225	0.21
ease of checking completed tasks	33	9	0.14	256	10609	0.02
ease of managing software (program code) versions	41	25	0.06	98	3025	0.18
Total	288	2470	1	1224	39482	1
Concordance coefficient	0.918			0.813		
Calculated χ^2	51.48			193.49		
Table χ^2(k=7, α=0.05)	14.068			14.068		

Table 4. Evaluation of the results of determining the effectiveness of a cloud-oriented environment for flipped learning.

Indicators	Teaching staff			Students		
	Rank sum	S	Weight	Rank sum	S	Weight
availability of training resources in a cloud-oriented environment	37	25	0.11	99	1369	0.19
completeness of educational material for students to acquire theoretical knowledge independently	17	225	0.23	207	5041	0.04
completeness of training material necessary for practical tasks	28	16	0.17	57	6241	0.25
convenience for independent preparation for the class	46	196	0.06	145	81	0.13
convenience of interaction of team members in practical activity	33	1	0.14	167	961	0.10
possibility of self-control	52	400	0.02	66	4900	0.24
convenience for checking	11	441	0.27	211	5625	0.04
Total	224	1304	1	952	24218	1
Concordance coefficient	0.728			0.748		
Calculated χ^2	34.944			152.592		
Table χ^2 (k=6, α=0,05)	12.593			12.593		

When evaluating the effectiveness of a cloud-oriented environment for the project activity, teachers singled out the following indicators as the most important ones: convenience of organizing teamwork, the ease of interaction of team members in team development, and the ease of planning for a team project. According to the students, the most important indicators are the ease of teamwork organization, the ease of interaction of team members during team development and the ease of managing software (program code) versions.

Evaluating the effectiveness of the cloud-oriented environment for flipped learning, the teachers noted that the convenience of checking the level of acquired knowledge, completeness of educational material for students' independent mastering of theoretical knowledge and completeness of educational material needed to perform practical tasks were the most important indicators.

5 Conclusions

In the course of the study, which lasted for 3 years, a cloud-oriented environment was designed to perform cross-disciplinary projects under the flipped learning technology in the process of training future IT specialists. The designed environment is a major component of the ecosystem of flipped learning. The theoretical and practical importance for achieving the goal of sustainable development for the quality education of future IT professionals is to justify the quality criteria of such an environment. The main functional components of such an environment are cloud services for professional activity, for the implementation of the technology of flipped learning and project management. The cloud services and tools used and the activities of the student and the teacher are identified at each stage of the cross-disciplinary project implementation. One of the most important results obtained during the study was the identification of performance indicators for the developed cloud-based environment model, which cover the functionality of the environment by 3 criteria, namely: for the professional activity, for the implementation of the flipped learning technology and for the project management. The analysis of the results of the survey of students and teachers on three criteria makes it possible to draw conclusions about the consistency of their opinions. However, some indicators are considered more important as seen by the students than by teachers. They are: the availability of learning resources in a cloud environment, the completeness of training material for practical tasks, support for various programming technologies, ease of managing software (program code) versions. At the same time, teachers highlight the following indicators with greater weight as opposed to students: the convenience of checking the stages of tasks completion, the ease of checking completed tasks, the flexibility of the environment, the completeness of material for the students' independent work. Equally important to both students and the teachers are the following indicators: support for project implementation processes, integration with other resources and services, ease of teamwork, ease of planning and interaction among project participants. Thus, the most significant indicators of e-environment performance for flipped learning in the team project implementation are identified. In the future, it is advisable to investigate the impact of the use of the developed environment on the formation of professional and personal competences of the students of IT profession.

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Personalization of learning through adaptive technologies in the context of sustainable development of teachers' education

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Abstract. The article highlights the issues of personalized learning as the global trend of the modern ICT-based educational systems development. The notion, the main stages of evolution, the main features and principles of adaptive learning systems application for teachers' training are outlined. It is emphasized that the use and elaboration of the adaptive cloud-based learning systems are essential to provide sustainable development of teachers' education. The current trends and peculiarities of the cloud-based adaptive learning systems development and approach of their implementation for teachers' training are considered. The general model of the adaptive cloud-based learning system structure is proposed. The main components of the model are described; the issues of tools and services selection are outlined. The methods of the cloud-based learning components introduction within the adaptive systems of teacher training are considered. The current research developments of modeling and implementation of the adaptive cloud-based systems are outlined.

1 Introduction

In the context of modern transformations of social and technological systems, ubiquitous digitization, rapid updating of content and contexts of learning, the emergence of new scientific facts, changes in professional standards, requirements and expectations of employers, a social demand is formed for educators who can constantly improve their competence for sustainable personal development. Training a new generation of educators able to work in a dynamic environment, adapt to constant change, form subject-subject relationships in the classroom, including the use of modern ICT, is an important task of educational institutions.

As stated in the Digital Agenda for Europe [1], about 90% of occupations currently require at least basic ICT skills. The complexity of the tasks assigned to teachers is since they must not only develop their digital competence, but also the competence of the students. They also need to develop the skills for self-development throughout life.

The modern demands for educators imply they should be able to select appropriate and apply effectively the emerging technologies in the educational process that allow personalizing the educational process as much as possible, to bring it closer to the learning needs of each student: multimedia resources, electronic educational game resources, adaptive technologies, etc. The constant updating of these technologies requires the modern teacher to be reflexive, able to critically evaluate one's abilities, to direct efforts for self-development and self-improvement.

Teachers' training is fundamentally taken in the context of lifelong learning. According to Organization for Economic Cooperation and Development (OECD) experts, about 94% of teachers from participating countries are involved in at least one professional development activity during a year. Often, such training takes place online, through non-formal or informal learning, during off-hours. In this regard, there is a need to integrate technologies that will maximize the effectiveness of teachers' competences development while minimizing time spent. Progressive in this sense are adaptive technologies that allow for personalization of learning and significantly improve the quality of education, optimize time and other resources.

The important accelerator of the progress in this field is the availability of the cloud-based platforms and tools that force the emergence of a new generation of adaptive learning systems.

The cloud-based adaptive networks and platforms provide the united framework for the integration of different kinds of educational services into the whole system. Just the cloud-based infrastructures and services that are aimed to provide the openness and flexibility of systems' design are the most appropriate for the sustainable development of teachers' education. The features of the cloud-based systems are to support the flexible selection and adaptive adjustment of their components for certain groups of learners' needs. These systems may be implemented for different subject

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domains, using the uniform platform and also, they are open for innovations and the current introduction of new and emerging technologies.

The cloud-based platforms are invariant as for the content of methodical systems realized by these platforms so the basic learning and research components may be revealed for the possible general prototype of such systems. The important issue is to design the system to fit most of all the aims of teachers' sustainable education and professional development. This caused the need to consider the general structure of the adaptive cloud-based system of teachers' education and reveal its basic components having in mind that the selection of services for each of the components and elaboration of methods of their use may be the separate task for the appropriate context.

The purpose of the article is to consider the state of the art, tools, and services of the cloud-based adaptive learning systems introduction in the context of sustainable development of teachers' training, outline the approach, the general model, the methods and prospective trends of their use.

2 Personalization of learning as a global educational trend

The formation of a cloud-based learning and research environment is a promising area of informatization of education, which is recognized as a priority by international educational community [2, 3, 4], and is being intensively developed in various fields of education, in particular, in the teaching of mathematics and informatics disciplines in educational institutions. Trends of the introduction of cloud technologies in the educational process for organizing access to software used for various types of teamwork, in carrying out scientific and educational activities, research and development, implementation of projects, exchange of experience, etc. have become particularly relevant [3, 5].

According to many Ukrainian scientists, the problem of modernization of the teaching process in secondary school is in line with the modern scientific and technological progress [6, **Error! Reference source not found.**]. In this concern, one of the main factors for improving the quality of training of pedagogical, scientific and pedagogical staff, the widespread use of innovative pedagogical technologies is the introduction of adaptive cloud-oriented systems in educational institutions [6, **Error! Reference source not found.**].

Personalization of learning is currently one of the world's leading educational trends [8, 9, **Error! Reference source not found.**, 11, 12, 13] and more.

Personalized learning is a pedagogical concept supposing that the emphasis in the educational process is shifted from the normative requirements, standards, etc. to the personality of a learner, taking into account his / her characteristics: inclinations, abilities, and talents, national and cultural context, etc.

Having analyzed the materials of the International Academy of Education, UNESCO [14], Microsoft (Microsoft Education Transformation Framework) [15], we highlight the main principles of personalized learning:

- *Active involvement*. It is the transition from the passive perception of information by students to problematic search, independence, and creativity.
- *Social participation*. It means the involvement of students in active participation in various types of group work, problematic discussions, group project activities, etc.
- *Meaningful activities*. This is linking the content of education to real life, drawing practice-oriented analogies, performing tasks related to solving everyday problems, etc.
- *Relating new information to prior knowledge.* It means that it is important to relate new information to previously acquired so that it does not displace acquired knowledge, but expand, deepen, facilitate the establishment of logical, interdisciplinary links.
- *Being strategic*. In today's world of super-fast updating and dissemination of information, it is important to develop the younger generation's self-study skills, which lie not only in the learning itself but also in the ability to plan and control this process, build effective strategies, own educational trajectories of life, find educational information and critically evaluate it, establish cause and effect relationships, etc.
- *Engaging in self-regulation and being reflective*. It means forming the need and knowledge to carry out self-evaluation, critically assess one's own level of knowledge, competence, using various means (including adaptive assessment), monitor learning outcomes, plan activities to fill in the identified gaps, etc.
- *Restructuring prior knowledge*. It is in avoiding that prior knowledge and experience interfere with the acquisition of new educational material (for example, to explain to children that the Earth is "round", whereas the human eye perceives it differently). It is advisable to introduce new knowledge based on already known facts and to support them with scientific evidence.
- *Understanding rather than memorization.* It is important to orient students to understand the general principles, concepts, instead of mechanically memorizing individual facts and algorithms. This is a condition for effective learning. Leading international monitoring studies (such as PISA) are built on this principle – not just the knowledge of the curriculum, but their understanding, ability to apply the knowledge effectively in practice.
- *Time for practice.* It is important to take the time to practice in the learning process to consolidate one's skills and improve them. Forming individual skills (such as reading and writing) is impossible at all without long-term management.
- *Developmental and individual differences*. In the educational process it is necessary to account for the individual characteristics of each student. These features can both enhance the student's ability (e.g., aptitude for the sciences, disjointed spatial thinking, etc.), and may impose some limitations (for example, for a student with special needs). Therefore, it is important to offer a wide range of tasks and formats, including self-assessment

and self-evaluation that will motivate each student. This principle is best met by adaptive technologies.

- *Creating motivated learners*. Students' interest, their motivation in getting high results is a prerequisite for successful learning. Therefore, it is important to help in the proper arrangement of accents, goals, to choose tasks of adequate complexity (not too simple and not too complicated), to create situations of success, to avoid comparisons of students with each other, to support, including emotional factors, etc.

As we can see, the principles recognized by world experts (in particular, UNESCO) are more in line with the classical didactic principles, on the one hand, and reflect the genesis of approaches to learning: from passive to active participation, from routine memorization to creative knowledge, from the role of the teacher-translator of knowledge to the teacher-facilitator, from the precise use of technologies to their organic integration into the educational process.

In the context of the personification of learning, the educational process is designed following the principles outlined with the use of technologies that facilitate their effective implementation. Generally, truly personalized learning appears to be possible regarding the rapid development of the IT field. The development of technology has naturally led to the development of education on the way of personification, acting as a kind of catalyst and an integral part of this process. Means of support for the personification of the educational process include adaptive technologies that adjust the tools, resources and the content to the student needs in real-time, as well as provide him and the teacher with the analytics of the educational process.

3 Evolution of technologies for personalized learning

An important feature of adaptive cloud-oriented systems is the ability to dynamically supply computing resources and software and hardware, and its flexible customization to the needs of the user. With this approach, access to various types of educational software is organized, which can be either installed specifically on a cloud server or provided as a public service (available on any other electronic data media available via the Internet) [3]. Therefore, it is necessary to study the question: what are the ways and models of pedagogical activity, how are the role of electronic educational resources (EER) and approaches to their design changing, what are the means, models and ways of organizing access to them given the existing trends of cloud-oriented environment design and use in educational institutions. In this regard, the definition of conceptual backgrounds, features of creation and application, trends and ways of implementation of this class of systems requires careful analysis.

The adaptability of educational systems is achieved through the use of technologies that enable the automatic adaptation of these systems to the educational needs of different categories of users or the individual characteristics of learners. They can be customized depending on the level of education; educational role (student, teacher, researcher, etc.); the level of educational achievements; personal abilities, giftedness; educational needs (including special needs), etc.

To implement the computer-processing functions of a cloud-oriented system (content-technology and information-communication), a virtualized computer-technology (corporate or hybrid) infrastructure must be purposefully created.

Personalization is ensured by the possibility of customizing the ICT infrastructure (including the virtual one) to the individual information-communication, information-resource and operational-processing needs of the participants of the educational process.

Knowledge modeling tools and approaches developed in the field of artificial intelligence (AI) provide new applications in the design of computer-based training systems in connection with the development of such promising technologies as distributed knowledge bases; data repositories and shared knowledge; multi-agent technologies that enable the collective solution of tasks in a multi-user environment that communicate with each other as they exchange information and interact with software agents to support many intelligent functions.

The main stages of the evolution of adaptive cloud-oriented systems in education are shown in Table 1.

Table 1. The main stages of the development of adaptive learning systems.

Stage name	Period	Computer systems implementations	The role of modeling in stage formation
Programmed learning	1960s	Low-level programming languages (assembly language)	Thinking models in the form of algorithms
Educational programs	1960s - early 1970s	High-level programming languages (BASIC, Pascal, Algol, C), GUI	Black box thinking models
Educational systems of artificial intelligence	the late 1970s	Artificial intelligence languages (Prolog, Lisp, etc.)	Thinking models based on knowledge representation
Simulation of knowledge modeling, adaptive control	1980s – 2010s	Artificial intelligence Languages, object-oriented programming languages (C++, Visual Basic, etc.), multimedia	Simulation models of thinking and knowledge
Adaptive cloud-based systems	2010 is our time	Server virtualization hardware; adaptive networks (linguistic (Semantic Web), intelligent network agents, robots, etc.)	Combining knowledge models and their representation in adaptive networks

With the use of cloud technologies, the amount of computing power is increasing significantly, and the information and analytical tools that can be used to collect and process data that characterize student activity

are being improved. The emergence in the last decades of methods of programming natural language dialogue, strategic planning, and teacher modeling testifies to the emergence of a separate phase, which is defined as ATM (Adding a tutorial model), computer systems with the teacher model [16].

It can be assumed that the further development of computer-aided learning will be in favor to improve the knowledge models that underpin it [17]. That is, as these tools acquire an increasing degree of intellectualization, they will increasingly approach the modeling of more or less holistic fragments of the educational space and particular types of educational interaction.

4 Current trends in the development and use of adaptive learning systems in teacher education

Adaptive software and platforms with several benefits have been tested in various educational and socio-cultural settings and are now widely used in the global educational space:
- *curriculum platforms:* Alta[a], Cerego[b], Fishtree[c], Fulcrum Labs[d], LearnSmart[e], RedBird Advanced Learning[f], Socrative[g], Smart Sparrow[h]);
- *adaptive learning management systems (LMS), creation of training courses* (Neo LMS[i], Open Learning Initiative (OLI)[j]);
- *adaptive testing systems* (Typeform[k], Quizalize[l]);
- *adaptive math's training programs for elementary school students* (DreamBox[m], i-Ready[n], LearnBop[o], SuccessMaker[p], ScootPad[q], Splash Math[r]);
- *adaptive mathematics training programs* (KnowRe[s], LearnBop[t], Matific[u], ST Math[v], Think Through Math[w]);
- *Adaptive Adult Learning Platforms* (Elevate).

Today, Knewton is one of the most recognized and effective adaptive learning programs in the world. It is based on a nonlinear knowledge graph that connects concepts; analytics for teachers and students; personalized recommendations for teachers and students. In addition to the results of the assignments, the system also allows you to determine student's proficiency ("skill"), engagement ("involvement"), active time (how much student spent time to complete the task), time to complete the material to the end. The system generates statistics for both student (personal progress) and educator (individual student and group progress). Besides, based on the data obtained, the system provides recommendations: on which topics to work more carefully (for the student), what tasks for which topics it is advisable to offer for better mastering the material (for the educator) [18]. Arizona State University, which has been using Knewton technology since 2011, noted that the dropout rate dropped from 13% to 6% and those who completed the study increased from 66% to 75% [19], which attests to their effectiveness.

In the United States, Synaptic Global Learning, in collaboration with the Center for Innovation and Excellence in eLearning at the University of Massachusetts (USA), developed the world's first adaptive MOOC (Comprehensive Molecular Online Course) in Computational Molecular Dynamics, called aMOOC. The aMOOC platform provides powerful pedagogical support and a personalized learning environment based on Amazon Web Services cloud architecture [20].

In the US at Aspire Public Schools, teachers use adaptive technologies as a means of supporting blended learning. They use digital tools, discuss, learn about their achievements, participate in a strategy to improve their outcomes and overcome challenges [21].

Studying this problem, it is necessary to characterize to what (or to whom) these systems should be adapted, what characteristics should be investigated and taken into account when constructing a user model. In addition to the user model, the system also stores the user profile. The user profile stores personal information of users such as scientific (educational) benefits, training mode, and user knowledge. The model is based on profile research. A group of scientists from Croatia [16] explored the characteristics issues required when building a user model for adaptive learning systems. According to the research, individual users' characteristics were chosen as sources of adaptation. The result is a list of 17 characteristics that are considered sources of adaptation (age, gender, cognitive abilities, such as processing speed, long-term memory, spatial abilities, etc., metacognitive abilities, personality, anxiety, emotional and affective states, cognitive styles, learning styles, experience, background knowledge, motivation, expectations). According to the results, the adaptation of training systems increases when they are

[a] Alta: https://www.knewton.com/the-power-of-altas-adaptive-technology/
[b] Cerego: https://www.cerego.com/
[c] Fishtree: https://www.fishtree.com/
[d] Fulcrum Labs: https://www.fulcrumlabs.ai/
[e] LearnSmart: https://services.learnsmartsystems.com/sso/
[f] RedBird Advanced Learning: https://www.edsurge.com/product-reviews/redbird-advanced-learning-courses
[g] Socrative: https://socrative.com/
[h] Smart Sparrow: https://www.smartsparrow.com/what-is-adaptive-learning/
[i] Neo LMS: https://www.softwareadvice.com/lms/neo-lms-profile/
[j] Open Learning Initiative (OLI): https://oli.cmu.edu/
[k] Typeform: https://www.typeform.com/product/
[l] Quizalize: https://www.quizalize.com/
[m] DreamBox: https://www.dreambox.com/adaptive-learning
[n] i-Ready: http://i-readycentral.com/articles/how-does-the-i-ready-adaptive-diagnostic-work/
[o] LearnBop: https://www.learnbop.com/
[p] SuccessMaker: https://mypearsontraining.com/products/successmaker
[q] ScootPad: https://www.scootpad.com/
[r] Splash Math: *www.splashmath.com*
[s] KnowRe: *www.knowre.com*
[t] LearnBop: *www.learnbop.com*
[u] Matific: *www.matific.com*
[v] ST Math: *www.stmath.com*
[w] Think Through Math: *content.thinkthroughmath.com*

adapted to one or more of the following user characteristics.

According to English scholars [22] adaptability is a way of constructing a system of courses to model the interests of the user and apply it to adaptation based on the user's preferences. An adaptive learning system is a learning system that adapts the structure of the learning content to the individual learning characteristics of individual users.

In this regard, several important trends can be identified that characterize the promising avenues for the development and use of artificial intelligence and knowledge-based approaches in teacher education in the future:

- "intellectualization" of all units of educational systems, their further integration in the educational process and learning environment;
- intensive development and implementation of educational systems based on the latest achievements, methods, and developments of the AI industry;
- further unification, universalization, the formation of common standards for the development and implementation of individual modules, subsystems, and systems of educational purpose within the qualitatively new information and educational space with elements of artificial intelligence;
- increasing the role of the Big Data approach for collecting and analyzing the results of tracking learning processes and the individual progress of the learner;
- the increasing saturation of the learning environment with a variety of intelligent devices, remote controls, robots, peripheral equipment and the like, which can be managed on a single platform, over the network ("Internet of Things");
- increasing the role of computer literacy and technological culture of all participants in the learning process for the successful development and implementation of new generation AI learning tools.

5 Current research developments and future prospects

From 2018 at the Institute of Information Technologies and Learning Tools of the National Academy of Educational Sciences of Ukraine (Ukraine), a planned scientific study "Adaptive cloud-based system of secondary schools' teachers training and professional development" (2018-2020) is held.

The urgency of the work is due to the need to modernize the teaching process in the secondary school, bringing it into line with modern scientific and technological advances, which is the key to training highly qualified, ICT-competent teachers.

The purpose of the work is theoretical substantiation and development of an adaptive cloud-oriented system of education and professional development of secondary school teachers.

The main research results obtained during the implementation of the research, cover the following provisions:

1. The general model of an adaptive cloud-based system of education and professional development of teachers is proposed (Fig. 1). The model contains the components of corporate cloud of educational institution (databases and repositories, data analytics and pattern recognition tools, specialized educational software and services; educational robots, language processing tools, and others); public cloud services (usually it may contain office services; adaptive data and knowledge management tools, special learning and research cloud-based tools, electronic educational resources (EER) collections and EER elaboration tools and others; communication services (that may be either public or corporate); as well as the services of publicly available scientific-educational information networks and infrastructures. The separation of services between public and corporate cloud is conditional as it depends on services availability and educational needs.

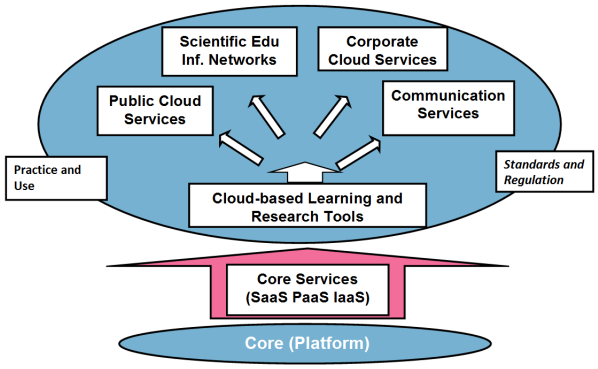

Fig. 1. The general structure of the adaptive cloud-based system of teachers' education and professional development.

The formation of modern cloud-based systems for supporting teaching and research activities and students' collaboration on the learning projects should be based on appropriate innovative models and methodology that can ensure a harmonious combination and embedding of various networking tools into the information-educational environment of higher education. The model of the CoCalc use to support various forms of collaboration in the process of training of pre-service teachers of mathematics (Fig. 2) consists of the following components: the organizational, the content and the technological ones.

The model was built on the basis of the general structure of the adaptive cloud-based system of teachers' education and professional development. The model includes teachers and students individual or collective spaces consisting of some structural elements. The combination of certain elements provides different types of interaction organization (between students and a teacher and between students with each other) among them such as individual and group work of students, students and teachers cooperation and active communication.

2. The methods for using the services of an adaptive cloud-based system of education and professional development of teachers, including the methods of using the services of a research-educational cloud based on

Microsoft Office 365 used for searching, submitting and processing data and information in open systems of study and research [5]; the method of using adaptive content management systems based on public cloud (Google Docs, IBM Box, Microsoft Office 365) to support collaboration in virtual teams; the methodology for supporting the processes of adaptive creation and use of electronic educational resources (WPadV4, AWS) are proposed. The last method is based on the utility model of using knowledge-management tools to design electronic educational resources proposed by S. Svetsky, O. Moravcik [23].

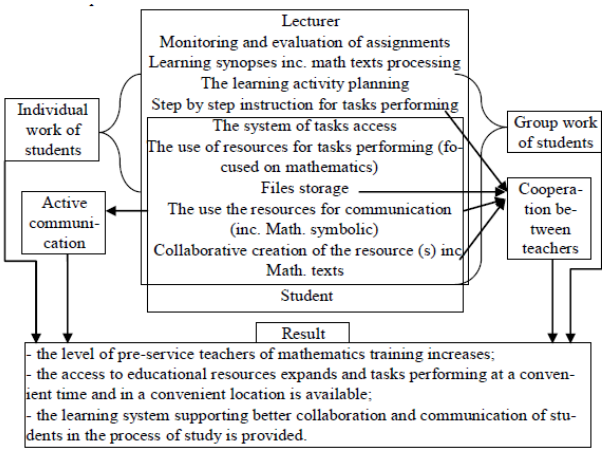

Fig.2. The model of the CoCalc use to support various forms of collaboration in the process of training of pre-service mathematics teachers.

To approve the application of different components of the adaptive learning system use the pedagogical experiment was undertaken. The experimental base of research was Kamyanets-Podilskyi National University named after Ivan Ogienko (Ukraine), masters of physical, mathematical, pedagogical specialties of a pedagogical institution of higher education, sample size – 160 students. The method of using Microsoft Office 365 tools, in particular, Microsoft Teams services to support students' collaboration and communication in the learning process and project elaboration was introduced. The Microsoft Office 365 was selected due to the complex of different educational oriented tools available in this package. It was essential to provide adaptability of the learning process and introduction of personalized learning techniques, in particular, while managing the students' team work. An alternative to using individual Microsoft Office 365 services may be FaceTime, for Apple gadgets - Google Duo, Hangouts. It was substantiated that due to the scientifically grounded and methodologically sound introduction of this method, there was a statistically significant increase in the level of ICT-competence and student performance (statistically consistent) [5].

3. It is substantiated that when designing adaptive cloud-based systems in a pedagogical university, it is advisable to use computer-based adaptive systems and platforms that have several advantages, tested in different educational and socio-cultural environments and are now widely used in the world educational space: curriculum platforms (Alta, Cerego, Fishtree, Fulcrum Labs, LearnSmart, RedBird Advanced Learning, Smart Sparrow, Socrative); adaptive learning management systems, creation of training courses (Neo LMS, Open Learning Initiative (OLI)); adaptive testing systems (Typeform, Quizalize); adaptive adult learning platforms (Elevate) and more.

4. It is determined that it is expedient to include cloud services of open science, in particular, services of European research infrastructures, in the composition of facilities and services of forming adaptive cloud-oriented systems in a pedagogical university; scientific and educational networks; cloud data collection, submission and processing services; as well as the services of the European Open Science Cloud.

5. On the basis of the proposed research the model of using CoCalc cloud service as a tool of forming professional competencies of the mathematics teachers was approved, taking into account the links between the components of professional competencies and all cycles of the disciplines of the mathematics teachers' training programs for pedagogical universities. The use of the cloud service CoCalc proved to be effective at three stages of the development of professional competencies. It has been found out that the use of this cloud service in the process of pre-service training of mathematics teachers affects first of all the formation of special professional competencies.

The analysis of the results of the forming stage of the pedagogical experiment showed that the distribution of the levels of the formation of professional competencies in the experimental and control groups of mathematics trainee teachers has statistically significant differences due to the implementation of the developed method of using the cloud service CoCalc, which confirms the hypothesis of the study.

The expediency of introducing CoCalc cloud service to the process of teaching mathematics and informatics teachers is substantiated within the research, that accounted for certain peculiarities of content formation of several mathematical and informational disciplines, other approaches to solving classical problems. The CoCalc service was used to provide adaptive learning and personalized approach, organization of students' teamwork and it was used due to its free license. Differentiation of the tasks will help to include in the educational process more tools that are presented in the cloud environment: Chatroom, LaTeXDocument, ManageaCourse, TaskList, and not only the most common resource – the worksheet. The results of this application were approved by the pedagogical experiment, undertaken in Kryvyi Rih National University, Ukraine. It was proved that the level of students' professional competencies would be higher if to introduce into the learning process the proposed method of using CoCalc cloud service.

In 2019 the results of the different aspects of the study were tested at 28 scientific and practical events: 6 conferences (4 international ones); 17 workshops (1 international). The problematic issues of scientific research were discussed and presented for the scientific and pedagogical community by organizing and

conducting by the authors a series of training sessions, seminars, webinars for scientific and pedagogical staff, and graduate students.

6 Conclusions and discussion

1. It is advisable to include the components of the corporate and public clouds of the educational institution (databases and data collections, adaptive content management systems, cloud-based office software applications, specialized software training tools, language processing tools, educational robots, and others) as well as services of publicly available information systems (scientific-educational information networks and infrastructures, cloud-based educational, scientific services) into future teachers training.
2. In the general model of the adaptive cloud-based system of education and professional development of teachers the components of the public and the corporate cloud of the educational institution are distinguished, as well as communication services and scientific and educational information networks. As now the hybrid cloud-based solutions are at demand there is no strict limitation of what kinds of the services would belong to any of the public or the corporate parts. The proposed model only provides the general structure and approach for the services supply. The important issue for further research is consider and build different configurations in view of the basic principles and approach. The experimental design was based on several available services for the different components of the general model that was outlined. Still the set of the services is not still exhaustive in any case.
3. In the process of designing an adaptive cloud-oriented system of education and professional development of teachers of general secondary education, it is advisable to use the methodology of using the services of a scientific-educational cloud of an educational institution based on Microsoft Office 365, Google services and other; to use adaptive content management tools based on a public cloud; to implement methodology for supporting the adaptive knowledge-based processes of creation and use of electronic educational resources and other kinds of services within the outlined framework.

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Formation of practical skills modeling and printing of three-dimensional objects in the process of professional training of IT specialists

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Abstract. The article discusses the current technology of three-dimensional modeling and prospects for its implementation in the structure of the modern system of professional training of IT specialists according to the concepts of sustainable development. The problems have been actualized and the methodology for three-dimensional modeling and printing has been proposed by using modern software, in particular, the features of using the basic core of geometric design and software preparation of the model for printing have been presented. An algorithm for the formation of practical skills of students in hardware preparation and calibration of 3D printers, the adjustment of the main technological parameters of work, preparation for the manufacture of a spatial model has been proposed. The developed algorithm promotes to the formation of practical skills of modeling and printing three-dimensional objects in future IT-specialists of vocational education, contributes to the formation of their professional competencies. In turn, this contributes to the formation of professional competencies among future IT specialists and creates the need for systematic improvement of knowledge and their creative implementation in practice with a more efficient use of IT technologies, which is the basis in solving the problems of sustainable development of society.

1 Introduction

1.1 Formulation of the problem

Effective and innovative development of the modern information society is impossible without a comprehensive solution to global problems, which solutions are indicated in the ideology of the Sustainable Development Strategy. So, the need arises to ensure a balance of three components: environment-nature, society, and the economy with the priorities of reasonable, sustainable and comprehensive growth [1]. Under such conditions, vocational education and training are the key prerequisites for achieving sustainable development of society, and also a tool to increase the competitiveness and mobility of the country's labor potential [2].

The importance of solving this issue is reflected in the main legislative and regulatory documents of the country. Actual problems of training future specialists in vocational education in the field of computer technology are reflected in the Law of Ukraine "On Higher Education", the National Doctrine of the Development of Education, and industry standards for higher education. The conceptual provisions of vocational education in the context of society's informatization are set forth in the Law of Ukraine "On the National Informatization Program", the Concept of the National Informatization Program, and the State Program "Information and Communication Technologies in Education and Science", which states that ICT is "an element of the new infrastructure, the main factor in accelerating innovation processes and modernizing the economy" [3].

The peculiarity of the development of the modern information society lies in the phenomenal growth of the possibilities of information and communication technologies (ICT) and their continuous implementation, which has significantly changed the situation in many parts of human activity, including in the field of professional educations. A special place in the educational process of preparing bachelors and masters is given to the study of normative and selective disciplines that provide theoretical knowledge and practical application of three-dimensional modeling software products [8].

Along with a thorough study of the basic command tools and algorithms for constructing individual spatial elements, professional modeling tools and computer design technologies, insufficient attention is paid to modern technologies for the application of such software products. The lack of practical use until recently was caused by a number of reasons, among which, first of all, the lack of material and technical base that would ensure the implementation of the manufacturing technology of designed products in the design process.

With the advent of affordable technical means of production (CNC-machines, 3D-printers), opportunities have grown to better quality training, however, the

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intensification of development in this direction has been delayed in default of the absence or imperfection of training algorithms. By the term "educational algorithms" we mean a system of sequences of application of methods and tools that increase the quality of training of future specialists of a certain professional industry, which provides for a comparison of the goal and the actual result of the educational process.

Studying the basics of computer graphics and modeling is becoming one of the most important areas for training specialists in IT technology with a developed set of creative abilities, who are ready for self-development and self-realization and who are fluent in 3D modeling skills.

1.2 Research analysis

Famous scientists in the field of information technology, in particular, V. Bykov, M. Zhaldak, M. Leshchenko identified the main characteristic features of the content of computer literacy and revealed the methodological aspects of teaching information modeling [3, 7]. The domestic and foreign research thoroughly covered the problem of application of modern technologies of geometric modeling in the learning process [5-8]. The problems of the applied application of three-dimensional modeling and printing technologies are also disclosed [4, 9]. An analysis of the scientific and pedagogical literature indicates that the problem of the practical training of specialists remains one of the most actual.

An analysis of theory and practice indicates that the level of practical skills of young specialists is insufficient and does not meet international standards and the requirements of the modern labor market, which negatively affects the quality of their professional training [10]. Therefore, we believe that the features of studying three-dimensional modeling and printing in the process of practical training of future specialists in vocational education should be disclosed in more detail. This is due to a number of contradictions: the need for consistent, targeted involvement of future specialists in professional practical experience in the conditions of informatization and the lack of educational technologies for the formation of their professional culture; the increasing role of project activities in the professionalization and socialization of young professionals and the low level and fragmented nature of its formation in the learning process using traditional technologies; requirements of employers to the level of information and communication competencies of graduates, but not the sufficiency of appropriate scientific and methodological support.

In our opinion, an integrated approach to the formation of the necessary level of their practical training and information culture as a whole will significantly improve the quality of training of future specialists in vocational education in the field of IT technology.

The research purpose: to disclose the algorithm of three-dimensional modeling and printing of spatial objects to form the practical skills of future specialists in vocational education in the field of IT technology.

Object of study: formation of practical skills of future IT specialists using the tools of modeling technology and printing of three-dimensional objects.

2 Research methodologies

To conduct the study, an analysis of the requirements for specialists in the field of computer technology in the modern labor market (work.ua, jobs.aol.com, rabota.ua, etc.) was made. The competencies provided by educational programs, which a qualified specialist should possess, are also analyzed. Based on a comparison of educational goals and requirements for specialists in the labor market, the most relevant areas for improving the process of forming practical skills of future specialists in vocational education in the field of computer technology were identified.

In this regard, an analysis of three-dimensional modeling technologies was carried out, which are the most common and in demand at the present stage of development of information technologies. The study involved the application of methods for analyzing the requirements for specialists in the field of computer technology and the knowledge of this problem, a comparative analysis of software products of three-dimensional graphics, a generalization of the results.

3 Research results

In modern conditions of modernization of education, students of higher educational institutions (HEI) need to learn an increasing amount of educational material in order to become competitive specialists in the field of their professional activity. It is a question not only of a quantitative accumulation of knowledge, but also of a qualitative restructuring of the entire system of educational activity of the HEI. The constant replenishment of not only knowledge, but also professional skills, throughout life becomes now necessary for any specialist. Particular attention in the educational process is acquired not by transferring certain knowledge to students, but by developing future specialists' needs for their constant replenishment, the formation and consolidation of practical professional skills [11].

Therefore, it can be argued that the main objective of the HEI is the professional training of competitive specialists with professional skills and the ability to work creatively and proactively. In turn, vocational training is the acquisition of qualifications in the relevant specialty, which in the future, based on the general fundamental foundations of the educational process, supplements them with specific specialized competencies, reflecting the characteristics of a particular field of activity [12].

In order to form a high-quality practical training of specialists in vocational education, we consider it necessary to take into account the features of the process

of modeling and printing three-dimensional objects using the example of building an architectural object. This is due to the specifics of the professional skills of future specialists in vocational education in the field of computer technology – their diversity and interdisciplinarity.

Consider the process of designing three-dimensional objects by means of computer-aided design (CAD), which includes the following stages: analysis, the formation of technical specifications, topological description, the synthesis of array alternative structures, geometric modeling, analysis of results, optimization, generation and transmission of information for manufacturing on a 3D printer [13].

Considering the production technology and taking into account the type of the simulated object (in this case, the engineering one), the stage of geometric modeling always occupies a special place in the structure of the general design technology, due to its complexity and considerable complexity. The creation of a three-dimensional model of the future product is implemented by a wide variety of 3D-modeling programs, among which the SolidWorks environment occupies a special place.

SolidWorks [13] has sufficient command tools for creating spatial objects of varying complexity. Particular attention should be paid to the study of the sketching environment by students, the features of working with linear and curvilinear graphics, editing tools (curves, chamfers, scaling, mirror reflections), determining the geometry of sketch objects (dimensions, geometric constraints). This greatly expands the applied practical skills of students and reduces the complexity of their activities.

The study of three-dimensional graphics is based on the basic methods of forming spatial elements and provides a detailed analysis of the features and functionality of each of them through a detailed study of instruction managers (sliding windows, panels, additional modes, etc.). Particular attention must be paid to the model building algorithms using the build manager, the ability to correctly evaluate geometry, which can often be complex and determine the method of creating the foundation and the sequence of further modeling and editing of the future product.

In general, generalized 3D modeling technology involves the step-by-step creation of individual elements, starting with sketches, creating a spatial base model based on them, forming and editing spatial elements and categories (fig. 1). In this case, the model includes a relief inscription of the university abbreviation, which has been presented in Cyrillic (fig. 2).

The three-dimensional model created in this way can be used by modern systems and CNC (computer numerical control) processing technologies using the SolidCAM modular environment [14], with which you can develop the manufacturing technology of a product modeled in SolidWorks, from metal or wood.

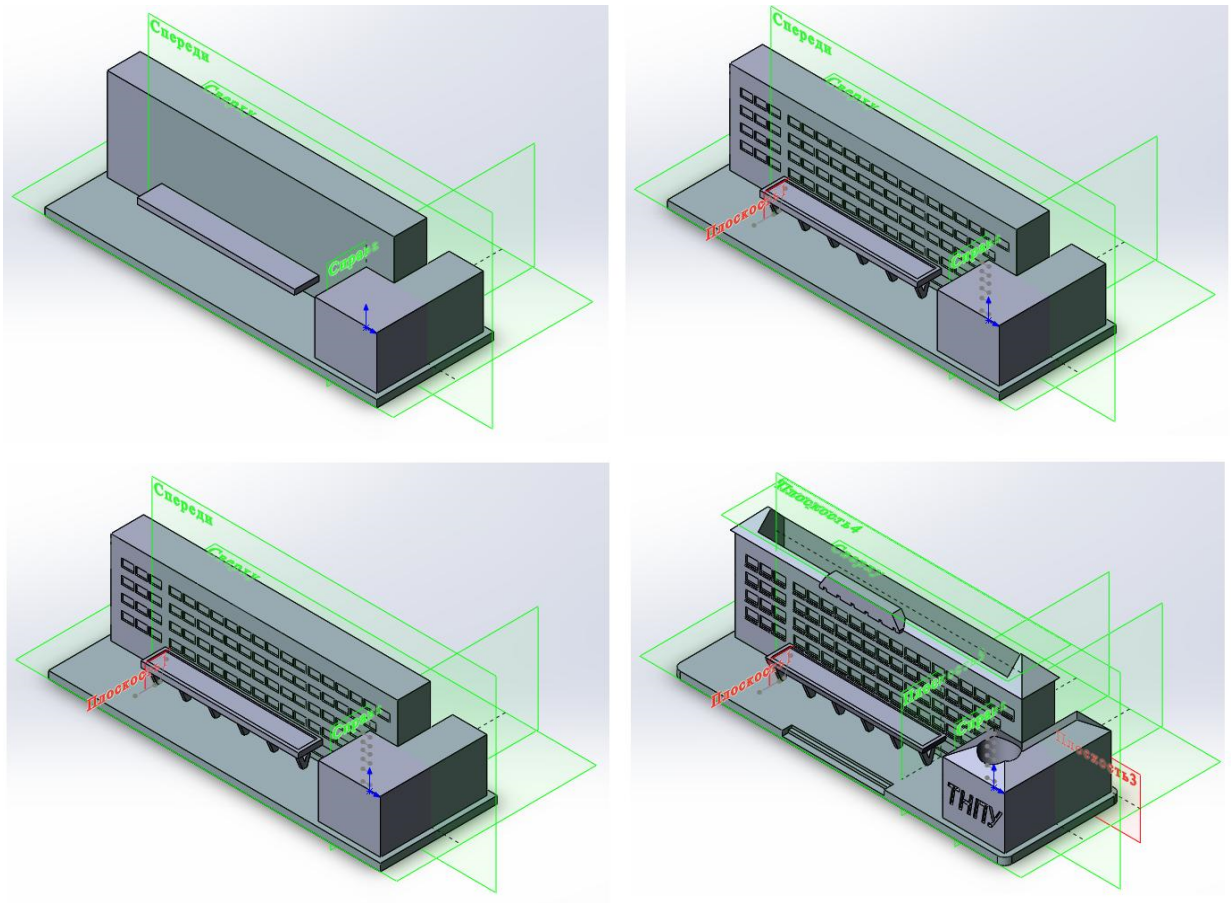

Fig. 1. The stages of creating a spatial model of the product.

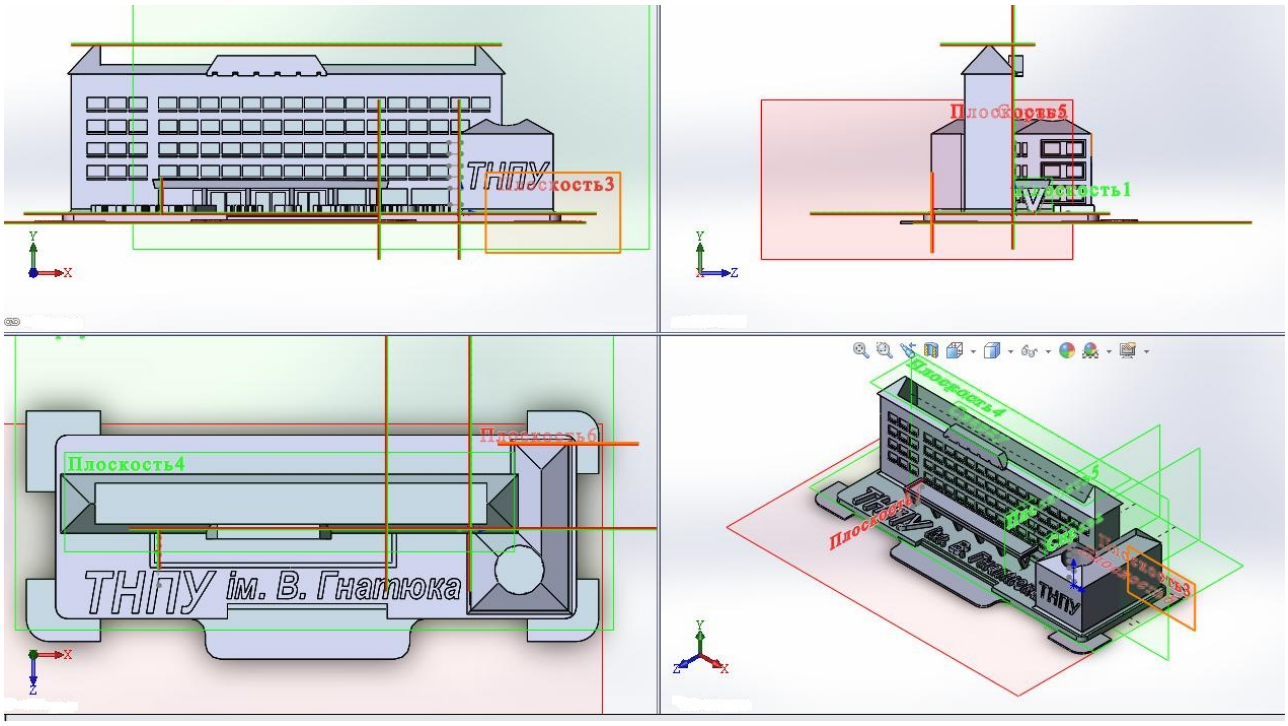

Fig. 2. The completed view of the spatial model of the product.

In this case, according to the task, we consider the features of manufacturing a model of plastic mass. The manufacture of these types of products is quite successfully implemented by the technologies of software and hardware 3D printing, using plastic masses (ABS, PLA, nylon, etc.) as a material.

Today, there is a wide variety of 3D printing computer programs, among which are Kissslicer, Cura, Slic3r, CraftWare, 3DTin, Repetier-Host. 3D printing software includes computer programs for interaction with hardware device, drivers for the 3D printer, and also may include configuration files. It should be noted that the mentioned software products are quite common, some of them have advanced functionality and relative complexity. In order to select the appropriate software, it is necessary to analyze the software, that was mentioned above, in accordance with standard ISO 9126: 2001 by such parameters: functionality, usability, efficiency, program interface [15].

A comparative analysis of the mentioned software found that a significant advantage according to the criteria of convenience and an intuitive interface at the stage of learning 3D printing technologies is the Cura software environment, in which, in addition to standard tools (setting print quality, material parameters), the functions of calculating the mass of the finished product, printing time and the like are implemented also [16]. However, the Cura software environment, like other 3D printing support products, does not provide support for file formatting. The main input data format is the STL format, in which information is stored as an array of triangular data describing the surface and their normals.

Thus, the geometric model that is created in any 3D modeling software product must be broadcast in the STL format (Fig. 3). It should be noted that due to the intensive development of 3D printing, most CAD systems, including SolidWorks, support this function.

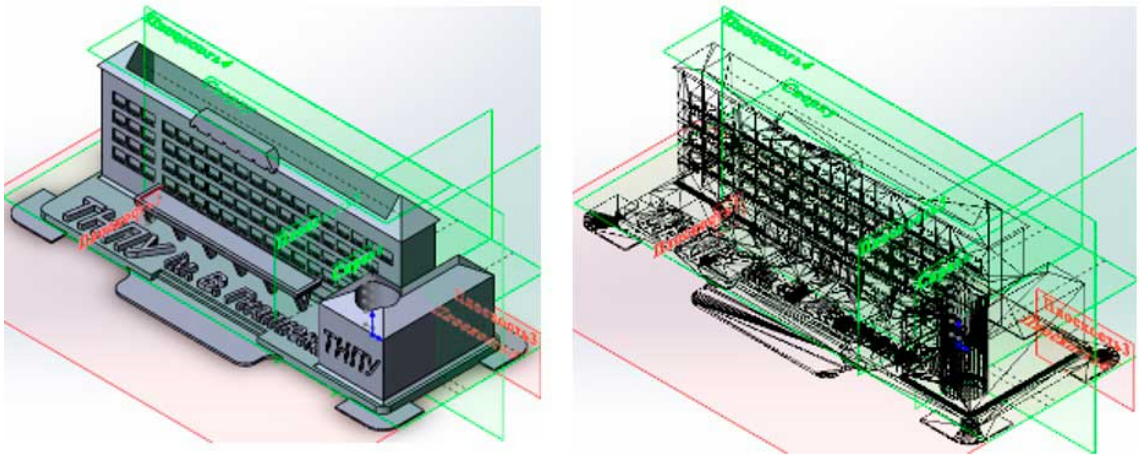

Fig. 3. Comparative model views in * .sldprt format (SolidWorks format) and * .stl

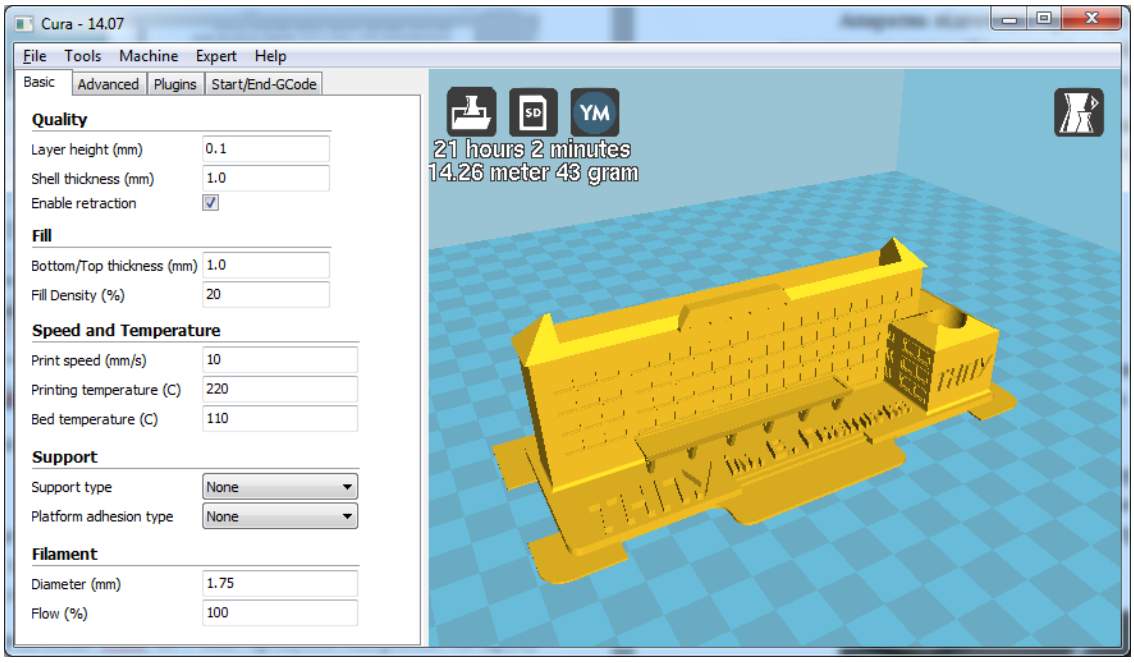

Fig. 4. The Cura software interface and downloaded model in * .stl format.

The technological parameters of printing is the Cura software environment are configured on the *Basic*, *Advanced*, *Plugins*, *Start and End G-codes* tabs (Fig. 4). The basic settings are located on the *Basic* tab: print quality, filling, print speed and temperature, print support options for the model and plastic thread.

When setting the print quality parameters, the determining indicators are *Layer height* (*mm*), which should not exceed 1/2 the nozzle diameter of a 3D printer. For a filament thickness of 1.75 mm and a nozzle diameter of 0.4 mm, the maximum value of the layer thickness can be considered 0.2 mm. In order to obtain objects of improved quality, the layer thickness is recommended to be taken in the range of 0.1-0.15 mm, however, it is necessary to take into account the increase in the total printing time of the model.

Shell thickness (mm) – determines the wall thickness of the model when printing thin-walled objects or objects with a reduced fill factor. The practical value of the wall thickness is selected based on the specific geometric parameters of the object, but it is recommended to take it within 1-2 mm. A wall thickness value of less than 1 mm is considered insufficient to ensure minimum model rigidity requirements, however, for small-sized models (10-30 mm), this thickness can be considered optimal.

The thickness of the upper and lower walls is controlled by a separate indicator *Bottom /Top thickness (mm)*, which in the absence of special design requirements can be equated to the thickness of the shell. However, it is not recommended to accept this value less than 0.6 mm.

Economic indicators of plastic consumption and model stiffness are implemented by the *Fill Density (%)* indicator. By default, for most cases, the fill factor is 20%. However, if it is necessary to obtain rigid models, and also taking into account the design features of the model, the fill factor can be 100%. This significantly increases the consumption of material and printing. In the case of applying a fill factor of less than 10%, a significant decrease in structural rigidity and imperfections in printing can be observed.

Setting speed and temperature conditions provides high-quality and technological parameters of printing. The most determining parameter is the *Print Speed (mm)*, which determines the speed at which the nozzle moves and model builds. For printing models with overall geometric dimensions of 100-120 mm and the presence of small elements, it is recommended to set the speed parameter 10-15 mm/s. It is not recommended to set a speed of more than 25 mm/s due to a significant decrease in print quality, the appearance of vibrational forces on the supporting structure of the printer and the rapid wear of the drive elements.

The printing temperature (*Printing temperature (C)*) and the table temperature (*Bed temperature (C)*) of the printer must be coordinated with the type of plastic used. Support technology provides for the printing of additional (not provided by geometry) model elements, due to the impossibility of the formation of plastic mass in the air. Such support is implemented both for individual elements of the model (*Support type*) and its foundation (*Platform adhesion type*).

The settings of the plastic thread (filaments) are implemented by the obligatory condition of the numerical value of the diameter (*Diameter (mm)*) of the used filaments and the fill factor *(Flow (%)*). For modern technology of 3D printing, the use of filaments with a diameter of 1.75 or 3.0 mm is provided. When setting the fill factor, it must be taken into account that the maximum value can cause irregularities and, accordingly, nozzle strokes during printing, because the minimum value will cause the fragility of the printed model.

The *Cura* environment is actually a slider program, designed to convert the surface of a geometric array into

a sequence of slices by parallel planes with subsequent translation of the data into a G-code

G-code – the general name of a programming language, which is regulated by the relevant standard and is intended for programming equipment with numerical control. The model G-code file is the source information file for the hardware of the 3D printer and can be downloaded using the direct interface or using an SD card [17].

To visualize the process of layer-by-layer printing, the G-code of the model can be loaded directly into the *Cura* environment (Fig. 5). Using the slider tool located in the graphics area provides a layered display of the sequence of future printing of the model.

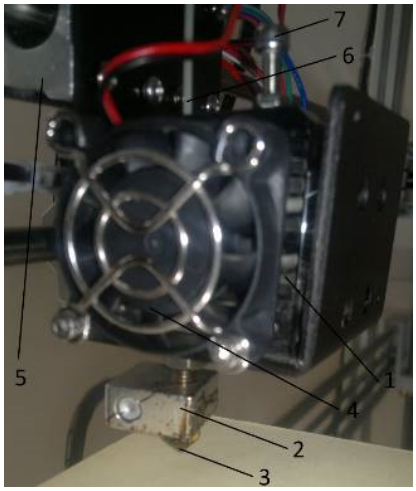

Fig. 5. General view of the print head of a 3D printer: 1 – gear module for filing the thread (inside the structure), 2 – heating element; 3 – nozzle; 4 – cooling fan; 5 – case with guides; 6 – plastic thread (filament) 7 – support screw.

The hardware preparation of a 3D printer should include the following steps: preparation of plastic filament (*filaments*), printer calibration, desktop preparation, downloading a model file, printing a model.

The first step in preparing the printer for hardware is installing filaments in the print head of the printer. Structurally, it is made in the form of a toothed filament feed module, a heating element, a nozzle, a cooling fan, and a housing with guides (Fig. 5).

The printer calibration technology provides for the formation of technological gaps between the working surface of the table and the nozzle in order to ensure high-quality layering of the plastic mass. The correct insertion of the plastic mass ensures its normal distribution, the correct adhesion of the initial and subsequent layers, while ensuring high-quality manufacture of the product. The necessary clearance is ensured by adjusting the screws of the desktop at four points along the perimeter. A prerequisite for this is the preheating of the printing table to operating temperature.

The preparation of filaments involves the release of the technological opening of the filament by pressing the support screw, threading the end of the filament into the feed opening of the print head, followed by capture by the gear module and filing the filament to the heating element.

The preparation of the desktop, in addition to calibrating the gaps, also includes the need to lubricate it with an adhesive to ensure the necessary adhesion of the first layer to the work surface, which is especially important when printing ABS models with plastic. In this case, glue on a PVP basis can be recommended. It should also be noted that for PLA plastic such a problem is not observed.

Downloading the model can be implemented using direct interface technology and using external memory modules (microSD). Printing a model is the final step that must be carried out only when all previous steps are completed. The downloaded file G-code of model, in addition to geometric information, contains data on the manufacturing process. So, after starting the model for printing, the extruder nozzle and the printer table are preheated. Information about the operation is displayed on the printer information panel (Fig. 6).

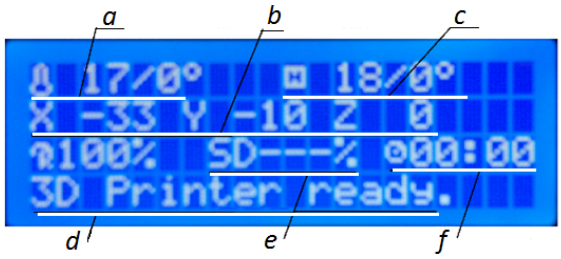

Fig. 6. Printer Modes Dashboard: a – nozzle temperature control; b – extruder position coordinates; c – table temperature control; d – printer ready status; e – the percentage of task execution; f – the total time of the task.

In the case of the preparation of technological operating modes, the 3D printer starts working. As a result, we get a finished product that fully corresponds to the created three-dimensional model in SolidWorks environment (Fig. 7).

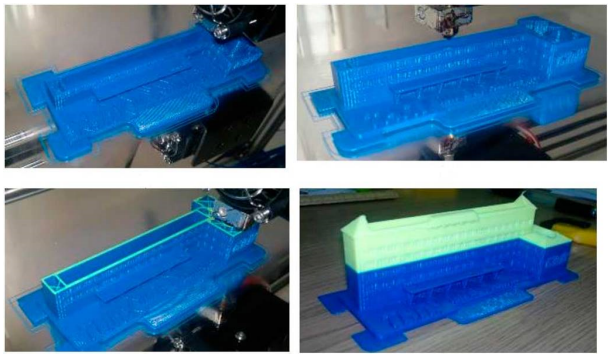

Fig. 7. Technological stages of printing a solid-state model.

Thus, the algorithm of three-dimensional modeling and printing can be divided into the following stages: modeling of the object, preparation of the data format and loading of the model, configuring software for printing the model, configuring hardware for the 3D printer, printing the model. Students' implementation of each stage of the algorithm involves the formation of certain skills and the acquisition of practical skills (Table 1).

To test the readiness of future IT specialists to implement the study of 3D printing technologies in the

educational process, experimental studies have been conducted with a group of students and the results of the input and final control have been analyzed. Carrying out such a study makes it possible to find out the level of students' practical skills of applying 3D modeling and printing technologies in the context of introducing modern IT technologies into the practical activities of future professional education specialists, according to the concept of sustainable development.

Table 1. Stages of the training algorithm.

Name of the stage	Basic theoretical knowledge and skills	Acquired practical skills
Modeling of object	Knowledge of the sequence and tools for work in a sketch environment, the ability to use commands to create 3D elements and categories	Creation of computer 3D models of objects of varying complexity degrees.
Preparing a data format for printing	Knowledge of basic graphic data formats, knowledge of data export procedure	Formation of the initial data of 3D models and preparation for printing
Hardware settings of 3D printer	Knowledge of the interface, structure and principle of operation of the main structural elements of a 3D printer	Calibration of 3D printer desktop and preparation of filament
Printing the model	Knowledge of coordinate configuring technology	Printing of products with strict observance of geometric dimensions and quality of surface

Analysis of the research results allowed us to establish that after conducting such classes, students significantly increased academic performance in academic disciplines, which include the study of computer modeling and three-dimensional visualization (Table 2), which indicates an increase of the level of formation of practical skills of students (EG – experimental group, N – the total number of students, μ_1 – the average score of students in the group, n – the number of students at level, IC – is the input control, FC – the final control).

Table 2. Dynamics of student performance.

Group	Stage	N	μ_1	Level of knowledge							
				High		Sufficient		Medium		Low	
				n	%	n	%	n	%	n	%
EG	IC	24	75,3	5	20,8	9	37,5	6	25	4	16,7
	FC		82,2	7	29,2	11	45,8	5	20,8	1	4,2

Accordingly, the quality of students' knowledge increased by 26.7 %, and the average score increased: $\Delta\mu E = 6.9$ (Fig. 8).

We believe that for the qualitative formation of practical skills of students in modeling and printing three-dimensional objects, it is necessary to introduce the study of such technologies as an essential component of their educational process. This contributes to the formation of professional competencies among future IT specialists and creates the need for systematic improvement of knowledge and their creative implementation in practice with more efficient use of IT technologies, which is the basis for solving problems of sustainable development of society.

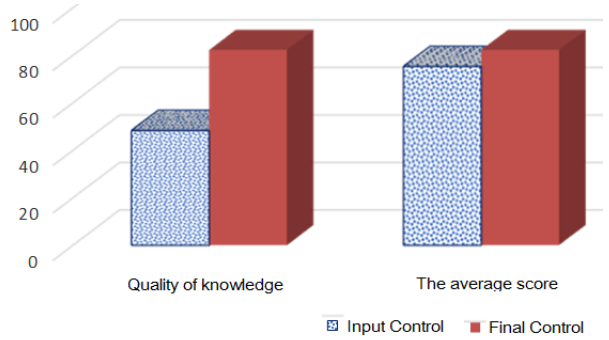

Fig. 8. The analysis of the experimental results.

4 Conclusions and future prospects

The key requirement for the training of IT professionals for the sustainable development of society is the formation of practical skills in using modern technologies, which allows them to develop their professional competence and increase their mobility and competitiveness in the labor market.

The organization of practical training and assimilation by students of a sufficient amount of knowledge defined by the curriculum programs, the formation of professional skills and competencies acquired by students in practical classes in the process of theoretical training, will further facilitate the easy inclusion of future specialists of IT technology in their professional activity.

Application of the developed learning algorithm contributes to the formation of practical skills of modeling and printing three-dimensional objects in future IT professionals. Thus, this contributes to the formation of professional competencies, makes it possible to foster steady interest in future professional activities, creates the need to systematically update their knowledge and apply them creatively in practice.

The presented algorithm can be successfully used also for technological purposes for the manufacture of three-dimensional objects for various purposes. The main advantage of using this technology for the manufacture of three-dimensional objects is the availability and low cost of manufactured models.

Prospects for further research are the development of methodological support for the formation of competence of modeling and 3D printing of spatial objects of complex geometric structure in future professional education specialists.

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The method of teaching IT students computer analysis of ergonomic reserves of the effectiveness of automated control systems

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Abstract. In the article, we consider a technique for training university students, who study IT specialties to solve problems of finding ergonomic reserves to improve the efficiency of automated systems. We describe the structure of the "Ergonomics of Automated Systems" course, software for evaluating and optimizing the activities of operators of "human-equipment-environment" systems, and methodological techniques for using ergonomic computer modeling to build effective automated control systems. Discipline is built using a man-system approach to the study and design of automated systems, when a person is considered the main element of the system, but the diverse influence of hardware, software and information support, as well as the environment, is taken into account. A significant difference between the developed method and similar existing disciplines devoted to the study of the "human factor" is that, firstly, not only the characteristics of the human operator working with technology are studied, but also the mutual influence of system elements; secondly, the course is based on a qualimetric approach to assess the reliability of the activity and the economic results of this activity; thirdly, the computer modeling used is focused on optimization with the use of economic criteria of activity, while observing the requirements of ergonomic norms and standards. Functional networks developed by the scientific school "Efficiency, Reliability, and Quality of Ergotechnical Systems" by Professor Anatoly Ilyich Gubinsky were used as a methodological basis for modeling and optimization of activities.

1 Introduction

Global challenges of the current state of ecology, politics and economics [1], an increase in the number of critical systems and industries, the growing losses from accidents and disasters, growing stress on people's activities due to increasing responsibility and the worsening mental health of the population all combine to question the prospects for sustainable development of the society [2].

The long-awaited automation of production, robotics and the introduction of artificial intelligence have greatly contributed to improving the efficiency of production systems management. However, they also brought a number of new problems [1]: social (unemployment, etc.); moral and ethical; reducing the reliability of complex systems in general; risks to the life and health of people, accidents, the growth of cybercrime, etc.

The euphoria from the ideas of unmanned production and the widespread introduction of robots begin to give a sober approach to determining the rational degree of automation, finding harmony between humans and robots and recognizing the need to pay more attention to the problems of the "human factor" [3-4]

2 Problem analysis and research objectives

The creation of irrational, difficult to operate and maintain machinery and equipment can lead to harmful social and economic consequences [4]. Today, most workers, especially young people, do not want to work in conditions that do not ensure safe and productive work.

Of course, if comfortable conditions for human interaction with technology are not provided, then it is unlikely that significant economic effect will be achieved [5].

Experience shows that ignoring the human factor in the creation of machines and automated systems leads to the loss of about 30% of their possible effectiveness [4-6].

Non-adaptive information technologies and production management systems cause accidents, huge material losses and even deaths.

It is possible to minimize the probability of erroneous actions of the personnel only based on systematic

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accounting of ergonomic requirements [7, 8].

Under these conditions, the ergonomic training of future engineers is of great importance [8, 9].

Such training can be conducted in many ways [8]:

- Training of professional ergonomists (bachelors, masters):it is carried out in many universities of the USA, Canada, Australia, Great Britain, Germany, France and other developed countries; it is implemented at several universities in Russia and Belarus; it is not available in Ukraine and in most developing countries.
- The introduction of disciplines related to the "human factor" (of ergonomic cycle) in the training programs for bachelors and masters of technical specialties (unfortunately, they often belong to optional disciplines).

A survey of graduate students (149 respondents from 5 universities of Ukraine), who study various specialties related to IT, automation of production processes and cybersecurity, has revealed [7]:

- Lack of motivation to study the discipline, lack of understanding of its role in the formation of IT-specialists ("it is more important to learn programming languages") – 89.75%
- Primitive ("common") understanding of "ergonomics" – 82.1%
- Lack of a clear understanding of the differences in subjects of the study of ergonomics and other sciences "on the human factor" – "engineering psychology", "labor protection", "scientific organization of labor", "design", "technical aesthetics", "cybernetics", etc. – 95.9%

Furthermore, the analysis of the difficulties in organizing the discipline of "ergonomics" for IT specialists is also associated with the unstable disciplinary system of science itself.

Most studies focus on local problems, such as: work environment factors[4,9]; functional state of operators[4,10]; anthropometry[9]; psychophysiological aspects of the activity[4,11]; interface design[6,17]; microergonomics [4,12];other[13-15].

If you study these particular questions in detail, you can miss the main goal - "The search for ergonomic reserves to improve the reliability and efficiency of computerized systems" [8, 16].

In addition, typical limitations for a large number of studies are [8, 18-20]:

- Purely humanitarian descriptive nature and the lack of an assessment of the quantitative characteristics of the reliability of human-computer interaction.
- Lack of an answer to a question like "what will happen if?" in relation to the impact of organizational and technical measures on the effectiveness of the system.
- Lack of focus on "organizational ergonomics" and on the formation of a program of measures to ensure an ergonomic quality system.

Obviously, the discipline may be useful and relevant if it answers questions such as "What measures to improve ergonomic quality should be implemented in the system in order to maximize profits (when meeting ergonomic norms and requirements)?"[21-23].

Thus, ergonomics should not be "costly" (as they say today), but "profitable" [8].

The most convenient theory that describes from the point of view of the human-system approach, methods for assessing and optimizing the functioning of "man-technology-environment" systems based on objective quantitative indicators, is the theory of functional networks of the scientific school of prof. Gubinsky A.I. [24-26]. In addition, within the framework of this scientific school, several methods have been developed for solving computer-based tasks for evaluating [27-28] and optimizing [29-30] man-machine interaction. Obviously, these developments can become the basis for this study.

Unfortunately, as a result of a review of well-known scientific research, it was not possible to find (even within the framework of the theory of functional networks) any convenient unified computer technology of "upstream (through)" modeling of the "human factor": from the model of a person performing a separate operation to assessing the reliability of the entire process of the human operator activities (taking into account all the influential factors), especially - the selection of the optimal system of ergonomic measures.

Based on the foregoing, we define the task of this work.

Formulation of the problem. Develop and describe the method of teaching the "ergonomics of automated systems" discipline for students of computer specialties based on the following principles: qualimetric modeling (on functional networks) of human-machine interaction; maximum use of computer variant modeling; the business case for the benefits of ergonomics.

3 Results

3.1 Discipline concept development

Figuratively, the goals of the discipline are defined as follows: "1. To convince future IT professionals that the application of ergonomics in IT is not only an important requirement of the international standards system, but also an important tool to reduce the risks of accidents and emergency situations and, as a result, to increase the profitability of the business; 2. To teach students computer modeling techniques for all processes of human-machine interaction occurring in automated systems in order to search for ergonomic reserves to increase the reliability and efficiency of automated control."

We define ergonomics as a science engaged in the comprehensive study and optimization of human activity in the "man-equipment-environment" system.

We offer the following level-based logic of discipline presentation, namely: "From studying specific characteristics of a person, equipment and environment to choosing organizational and technical solutions (through evaluation and optimization, using information technologies)".

Level 1: System-ergonomic analysis of "man – equipment – environment" systems:

- What you need to know about the characteristics of man; technology; environment?
- How to conduct a system ergonomic analysis?

Level 2: Modeling human-machine interaction:

- How to carry out: description of activities; performance assessment; optimization of activities?
- How to use IT to model human-machine interaction?

Level 3: Solving the basic tasks of ergonomics:

- How to solve the tasks of: ergonomic expert examination; designing working conditions; the choice of the level of automation (distribution of functions between the operator and the machine); determining the number of operators and their qualifications; distributions of functions between operators; designing information models; designing activity algorithms; professional selection?
- How to use IT to solve the main tasks of ergonomics?

Level 4: Economic justification of the ergonomic quality program.

Moreover, each subsequent level of presentation uses the knowledge and skills of all previous levels.

3.2 Development of the theoretical part of the course

The main goal of developing the theoretical part of the course was to form a new vision of the "Ergonomics of automated systems" discipline, which differs from the well-known, albeit high-quality, but usually "narrowly focused" technologies for studying the "human factor" (There are extremes: a human-centered approach (human at the forefront), a systems engineering approach (a person is an auxiliary element serving equipment), and an "equally elementary" approach (people and equipment are elements of equal importance)) focusing on a human-system approach, which considers a person to be the main element of the system, but at the same time takes into account all the features and structure of this system.

The task is to go from studying individual elements of the "man-technology-environment" system, i.e. features and characteristics of the human body, characteristics of technical means, and environmental factors, to modeling the system as a whole, and then to formalized description, assessing the reliability of activities and optimization of activities (with economic justification of the ergonomic quality assurance program).

In this regard, the following logic is proposed for lectures (sequence of topics):

1. The object, subject, goals, objectives and methods of ergonomics.
2. System-ergonomic analysis. Characteristics of the person, technology and environment.
3. Ergonomic requirements for the "man-technology-environment" system.
4. The severity of labor and the functional state of the human operator.
5. Principles of ensuring the ergonomic quality of the "man-technology-environment «system.
6. Workplace certification.
7. Ergonomic "man-technology-environment" system design support.
8. Ergonomic fundamentals of the functioning of the "man - technology-environment" system.
9. Description and evaluation of the algorithms of the human operator.
10. Optimization of human operator activity.
11. Ergonomics of information technology.
12. Ergonomic information technology expertise.
13. Usability.
14. Human-centered distributed information systems.
15. Ergonomics of critical systems.
16. Search for ergonomic reserves to increase the efficiency of automated systems.
17. Economic justification of measures to ensure the ergonomic quality of automated systems.

3.3 Development of the practical part of the course

The main goal of the formation of the practical (laboratory) part of the discipline was to develop 100% of the course topics by means of computer modeling using the technology of "what will happen if?" with the implementation of the principles of the training sequence (the gradual complication of the material and an increase in the number of factors taken into account - from the workplace to assessing the reliability of the activity) so that teaching students how to optimize the activities of operators taking into account ergonomic norms and requirements and the need to ensure the economic efficiency of the automated system became the logical conclusion to the course.

In this regard, we offer the following structure of the sections of the practical part:

- Certification of the workplace.
- Description and evaluation of the algorithms of the human operator.
- Ergonomic expert examination of information projects.
- Designing a system of measures to ensure ergonomic quality.

Each of these sections provides for laboratory work.

The first section includes three laboratory works.

1-st lab:

- Analysis of factors affecting the working environment.
- Definition of point estimates of working environment factors.

2-nd lab:

- Determination of the category of labor severity.
- Determination of performance indicators.
- Determination of correction factors for indicators of the quality of the human operator's activity.

3-rd lab:

- Development of measures aimed at improving the working environment.
- Business case for certification of workplaces.

The second section of the practical part of the course consists of five laboratory works that ultimately Describe, Evaluate, and Optimize algorithms of the human operator.

The third topic involves two laboratory works:

- Justification of the selection of characteristics that affect the ergonomic quality of information technology.
- Method of conducting expert examination and processing the results of expert work.

The fourth topic provides two final laboratory work topics:

- Economic justification of ergonomic measures (taking into account the whole complex of influencing factors: technology, environment, characteristics of operators, activity algorithms, motivation) for monoergatic systems (one operator)
- Economic justification of ergonomic measures for polyergatic systems (many operators).

3.4 The use of computer technology ergonomic research

3.4.1 Defining a development goal

As the experience of teaching future IT specialists disciplines focused on the "study of the human factor" has shown, students are extremely negative about declarative reasoning about the importance of applying ergonomic methods and even the need to use a system of international ergonomic standards if they cannot get specific values of indicators characterizing the benefits of systemic application of ergonomic methods.

In this regard, we set the task of developing and systematic application of computer technology that ensures the assessment and optimization of activities from assessing working conditions and the workplace of a human operator certification to evaluating indicators, such as: the probability of an error-free task (function), mathematical expectation and variance of the execution time of the task (function), probability of timely completion of a task (function), profit from the use of ergonomic measures, and further, to the solution of the corresponding optimization problems.

Based on this, we have developed a unified technology for end-to-end computer simulation of human-machine interaction, consisting of two interconnected subsystems, which will be briefly described below.

3.4.2 Computer technology for assessing working conditions at the workplace of a human operator

General characteristics of the program.

It implements the methodology [24] for assessing working conditions.

The software package consists of modules embracing:

- Support of reference data (a directory of sanitary and hygienic factors of working conditions, a directory of psychophysiological factors, a directory of categories of labor severity, a directory of correction factors for indicators of the quality of a human operator, measures to improve working conditions);
- Description of the sanitary-hygienic and psychophysiological factors of the working environment;
- Assessment of influencing factors according to a 6-point scale;
- Determination of the integral point assessment of the severity of labor, indicators of fatigue and performance;
- Determination of the category of labor severity and correction factors;
- Assessment of the impact of working environment factors on the quality of the human operator's activity;
- Reporting.

Features of using the program in the educational process.

The laboratory work to certify the workplace is carried out in two stages. At the first stage, a description of the working environment is introduced and initial values of the influencing factors are set. In this case, it is possible to select data from the directory. Data entry forms for filling out directories and an input form for describing factors of the working environment that represent the interface. For each given factor, a point score and an integral score are determined. Next, the category of labor severity is determined, which corresponds to the integral score obtained and the correction factor for assessing the influence of working environment factors on the quality of the human operator.

3.4.3 Computer technology for modeling the activities of a human operator

General characteristics of the software package.

The software package works in 2 modes.

In mode 1 (estimation), the probability of error-free execution and the characteristics of a random value of the execution time of the functioning algorithm (FA), as well as the probability of timely execution of the FA, are evaluated. The initial data that the user enters or selects from the database is the FA structure, as well as the reliability and lead time of individual FA operations. For given alternatives of the FA structure and (or) methods for performing individual operations - the choice of the optimal option (24 problem statements) including:

In mode 2 (optimization), with given alternative variants of the FA structure and (or) methods for performing individual operations, the best option is selected (24 problem statements), including single-criterion and multi-criterion ones.

The main modules of the software package: support for reference data; dialog entry of the description of the FA; automatic evaluation of the FA; variant analysis of the FA; FA optimization.

Using the software package in the educational process.

The software package is the basis of the laboratory work, the purpose of which is to acquire skills for the description, evaluation and optimization of the FA.

Such assessment is used in solving problems relating to: determination of the degree of automation; distribution of functions between operators; designing information models; designing activity algorithms, selection of measures of the system for ensuring ergonomic quality).

Consider, for example, the principle of solving the problem of choosing the optimal set of measures for an

ergonomic quality system (due to measures to improve working conditions in the workplace) – a monoergic system.

Formulation of the problem.

- The structure of the FA, a set of options for improving working conditions with known costs and the calculated error-response characteristics of the individual FA operations (through a system of correction factors that take into account the influence of the integral point estimate of the severity of labor)
- You must choose the option that provides the maximum profit from ergonomic activities.

Decision fundamental.

Reduce the functional network corresponding to the FA and "substitute" the values obtained taking into account the influence of the environment (working conditions), operator's qualifications, technical parameters as input data and thus determine the values of indicators for each variant of the system of measures: the probability of error-free execution of $B(k)$; mathematical expectation $M(k)$ and variance of runtime $D(k)$; probability of timely execution of $P_{rt}(k)$ (we accept the normal distribution law).

For each option k=1, n of the system of measures, determine the value of the profit indicator from the N-fold implementation of the algorithm according to the formula

$$C(k) = [P_1 B(k) P_{rt}(k)]N - [U_1(1 - B(k)P_{rt}(k))]N,$$

where

- P_1 is the amount of profit from a single timely and error-free performance of activities
- U_1 is the amount of damage from a single performance of an activity with an error or (and) untimely performance
- N is estimated number of planned executions of the algorithm
- k is option number of a system of measures to improve working conditions
- $C(k)$ is the amount of profit from the N-fold implementation of the algorithm.

For each version of the system of measures to determine the value of profit:

$$E(k) = C(k) - Z(k),$$

where $Z(k)$ is the amount of costs for events.

Such modeling allows convincing business managers and owners that ergonomic improvements are not only necessary to meet the standards and requirements, but are beneficial for the business.

3.5 Approbation

The developed course has been tested:

- In full at the universities: Sumy State University (Sumy, Ukraine); Sumy National Agrarian University (Sumy, Ukraine); Higher School of Technology and Energetics (St. Petersburg, Russia);
- Partially at the universities: National University of Life and Environmental Sciences (Kyiv, Ukraine, Kiev); Ukrainian Engineering-Pedagogical Academy (Kharkiv, Ukraine); St. Petersburg Electrotechnical University (St. Petersburg, Russia); Belgorod Agrarian Academy (Belgorod, Russia).

Moreover, the developed technology was used in the writing theses of bachelors and specialists and dissertations of masters and candidates of sciences. Among them, there are the works of graduates of Sumy State University devoted to the ergonomic support of machine-building production (Nikolai Bakhmach), chemical production (Alexander Skidanenko, Anastasia Fedorova and others), main gas pipeline management systems (Victor Koshara), outsourcing companies (Andrey Rokityansky, Alexander Barchenko, Dmitry Semenov, Eugene Plekhanov, Tatyana Shcherban, Julia Mikhailenko and others), information systems for various purposes (Julia Shapochka, Liliana Danilova, Andrey Kurochkin and others), e-learning systems (Evgeny Nikolin, Evgeniya Kaba, Nataliya Rudakova, Svetlana Vakal, Vitaliy Chernets, Anna Lebedka and others).

4 Conclusion

The aggravating problems of finding ergonomic reserves of the effectiveness of automated systems necessitate an increased attention to teaching at universities the methods that consider the "human factor".

Ergonomic training of a modern specialist in the field of information systems should include computer simulation of "man-technology-environment" systems.

It is convenient to evaluate the reliability of the human operator's activity using models and software tools that have been developed in the framework of the theory of functional networks of a scientific school of prof. A. I. Gubinsky.

The proposed training method based on information technology for modeling human-machine interaction allows you to teach students: methods for evaluating alternative options for organizing a human operator in information systems; techniques for solving the basic problems of ergonomics of automated systems; technologies for choosing a system of measures to ensure the ergonomic quality of information systems.

The scientific novelty lies in the fact that, firstly, in contrast to the well-known (usually purely descriptive) approaches to the study of human activity, for example, engineering-psychological or cybernetic, the proposed models take into account the interaction of all elements of an automated system (hardware and software, human and the environment) as well as form (taking into account all the influencing factors) the initial data on the quality of the individual operator's performance and alternative activity models in the form of functional networks and provide automatic assessment and optimization of activities.

Secondly, the developed teaching method is focused on qualimetric models, which makes it possible to search for reserves to increase the efficiency of automated systems.

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Improvement of the student evaluation system based on the ICT use

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Abstract. Today, considerable attention is paid to the higher education quality issues. The problem is solved by using tests that should provide a reliable student evaluation. The article presents the technology for improving test tasks. It includes functional procedures that specify the test and test task improvement sequence. It is found that it is better to use specialized computer applications for their implementation, that is why this technology involves the use of the author program "Statistical Analysis of Test Results". This program calculates the indicators – the item difficulty, discrimination, reliability and validity – according to empirical student testing data. The indicators help identify unsatisfactory quality test tasks and improve the student assessment means, as the program derives the recommendations. The steps set out by the testing result processing technology with the help of a statistical package increase the improvement process efficiency. The correlation and factor analyses help identify the tasks that put the highest load into the test score. These procedures influence on making a decision on the test task review need. The technology involves repeated checking procedures. The presented technology has been tested at Zaporizhzhya National University and Zaporizhzhya Regional Institute of Postgraduate Teacher Education. ANOVA has helped prove its effectiveness.

1 Introduction

The sustainable development is associated with solving problems that humanity will face in the near future. That is why ambitious goals such as providing universal and high-quality education; creating conditions that enable children to get free, equal and high-quality secondary education; ensuring equal access for women and men to high-quality education, including the university one; facilitating the students' acquisition of knowledge and skills necessary to promote the sustainable development are set before education [1]. According to the World Education Monitoring Report, learning helps solve global environmental problems, promotes economic growth, helps overcome gender and social inequalities and is considered to be a conflict and violence prevention means.

From the standpoint of higher education, the important issues are access, accessibility and quality. Access to higher education reflects a number of indicators one of which is the university entering preparedness level. In Ukraine, the level is determined by the external independent evaluation (testing) results, so the use of high-quality tests is very important. In addition to funding, accessibility is associated with higher education enrollment of differently-abled young people, including the disabled ones. The problem is solved by introducing information and communication technologies into the educational process that will enable to create comprehensive and effective learning conditions for everyone. And the use of computer-based testing expands the disabled students' education availability.

Achieving sustainable development goals is ensured by high education quality. Nowadays the future specialist training quality problem is considered by many researchers. The standard introduction in educational institutions, the use of learning practice research data, the inclusion of alternative qualifications in training, the communication with educational centers, the external evaluation implementation are considered to be the ways to improve the future teacher training quality [2]. To improve the future English Philology Masters' education quality, the innovation introducing new educational technologies and new learning methods into the educational process is important [3]. To improve the future programmer training quality, it is proposed to modernize the content and methods of programming learning in accordance with international standards; to develop variable modules taking into account the modern labor market standards and needs; to carry out the constant future software engineer training quality monitoring at all levels; to monitor the labor market in order to determine the employers' requirements and to adjust the training content in accordance with the latter [4].

The education quality is determined on the basis of the university ranking or according to the student

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performance results. As acknowledged by the authors of the report, university ranking is not a reliable way to determine the education quality and relates to the marketing tools [1]. A more reliable criterion is the student assessment that should be transparent and understandable. The testing as a way of knowledge level assessment is an essential and integral part of the operative intermediate, stage and final learning result assessment. This once again confirms that the relevance of research in this direction is a tool to reduce the student knowledge level assessment cost.

The evaluation is carried out mostly through testing with computer programs dominantly applied for its implementation. They are required to implement testing, obtain initial information, accumulate and store students' performance data. Such programs are computer knowledge testing systems (Brainbench, INDIGO, Hot Potatoes, MyTest, OpenTEST2, TCExam, etc.) and learning management systems (Blackboard, Inkling, MOODLE, Sakai, WebTutor, etc.). Most of them provide "technological testing cycle", that is preparation of the test task bank; test development; testing; testing result report making [5].

Nowadays the use of learning result testing computer programs is considered quite actively in terms of ongoing monitoring, final assessment and qualification examinations.

In the paper titled *Introducing Computer-Based Testing in High-Stakes Exams in Higher Education: Results of a Field Experiment,* the authors presented a comparative analysis of the use of the paper-based and computer-based tests in high-stakes exams [6]. The authors drew attention to the significance of the random test forming and the importance of using computer-based tests at the intermediate learning stage. The results of their study demonstrate that most students are ready to pass high-stakes exams based on the use of computer-based tests. Their positive attitude is explained by the possibility of getting a mark after passing the test.

The possibilities of using computer-based tests in the technical drawing assessment of students are discussed in *Development of Computer-Based Tests Mode of Assessment for Technical Drafting Students* by L. Aquino. The computer-based test development was carried out in four stages: Planning Stage; Development Stage; Validation and Acceptability Stage; Final Revision Stage [7]. The computer-based tests were analyzed and evaluated by five experts in the field of technical design according to the following parameters: Utility, Accuracy, Content and Navigation. At the same time, a computer-based test was evaluated according to the criteria of preferences in use, item difficulty level, readiness for computer-based testing and fraud prevention. As a result of the research, the author concludes that computer-based tests are appropriate and acceptable for technical drawing learning result assessment.

Recently, universities have been using learning management systems to enhance real learning opportunities. The use such programs enables students to study in a convenient place at a convenient time for them that is the basis for transforming the existing higher education system into Education for You [8]. The use of such programs is an adaptation of young specialists to passing qualification examinations that are already the base for the enterprise personnel selection. The learning management system opportunities are expanding by creating mobile applications that meet the challenges of the fourth industrial revolution. The use of mobile learning management systems will allow universities to refuse from traditional learning approaches, to implement innovations, and to form effective human capital [9].

Regardless of the means chosen for testing, all of them should implement an adequate learning result assessment and ensure the effective functioning of the educational process monitoring system. In this regard, the evaluation tool quality analysis and improvement is more relevant today than ever, regardless of the tools used in its implementation, whether by using a specialized program, with the help of a statistical package, or by formula calculation in a word processor environment.

These calculations are based on the Classical Testing Theory (CTT) and Item Response Theory (IRT) provisions. In general, the IRT results are considered to be more reliable than the CTT ones [10]. However, studies showing a link between the parameters obtained through these two theories have recently been conducted.

The paper titled *Validation of a developed university placement test using classical test theory and Rasch measurement approach* [11] presents a sequential economy test analysis that was conducted by using item difficulty, discrimination, and reliability indicators. Testing data was analyzed by using Classical Testing Theory and Item Response Theory. To calculate the CTT and IRT indicators, the authors used such specialized software as ITEMAN 4.3 and WINSTEPS 3.72.3. The data obtained proved a correlation between the results processed with the two models. It is important that the paper tested the task suitability to measure the desired result.

In the source [12], the authors considered the use of the CTT and IRT models in evaluating open test tasks. In order to obtain reliable results, open-ended test tasks were evaluated by experts and by using a developed scale. The estimates obtained were compared by using two models, and the open test task item difficulty indicators were calculated. The results demonstrated a high level of correspondence between them. The methods of mathematical statistics (factor analysis, correlation analysis, Che-square criterion) that proved the correspondence of the constructed model to the real data were used in the paper.

The paper titled *Comparative Analysis of Classical Test Theory and Item Response Theory Based Item Parameter Estimates of Senior School Certificate Mathematics Examination* [13] provides the mathematics examination result analysis by using the CTT and IRT methods. The indicators obtained by using the two theories were compared by the factor analysis methods (principal component analysis) and correlation analysis (Fisher Correction, Olkin and Pratt Correction, Point-Biserial). Factor analysis proved the unidimensionality

of all the tasks included in the examination. Correlation indicators indicated the absence of discrepancies between the item difficulty and discrimination indicators calculated by the two author-selected methods. The authors have also found that the item difficulty and discrimination indicators obtained are independent of sample size: n=100 and n=1000.

This review proves that statistical calculations (descriptive statistics, correlation analysis, statistical hypothesis testing, factor analysis, variance analysis, etc.) necessary to draw conclusions are used to carry out the test and test task analysis. However, the calculations turn into a big problem for teachers unschooled in mathematical statistics, and it is better to use a specialized program for this. Of course, nowadays there are specialized programs designed for test analysis [11, 14, 15]: Iteman, Winsteps, Test_Results, Computer-based system of quality analysis of test items etc. Some of these programs are local solutions that are not available to the general public: Test_Results, Computer-based system of quality analysis of test items.

Their functionality analysis has shown that they only output test quality indicators (in numerical or graphical form), and it is more logical to provide recommendations to assessment means developers. The availability of such programs cannot be a panacea to address the problem of improving the assessment means quality for students.

Hypothesis of our study. Based on a scientific publication and pedagogical experience theoretical analysis, we assume that the use of special technology to improve test tasks will allow: to gradually create adequate and reliable tests for evaluating student learning result assessment; to constantly check their validity; to implement the procedure efficiently and simply. To this end, we have developed specialized software.

2 Methods and instruments

The study hypothesis checking was carried out by using a set of methods. To determine the indicators necessary to improve the learning result assessment means quality, the methods of scientific and methodological literature data theoretical analysis and generalization were used. The analysis of the publications allowed to determine the test quality indicators. Their calculation is based on the test theory and statistical methods.

In the process of developing the test improvement technology, series of computational procedures were carried out that made it possible to select the most effective test theory and statistical methods. They are the test and test task item difficulty determination; task discriminative ability test; test reliability and validity evaluation; correlation analysis; factor analysis, ANOVA. Computational procedures used empirical student test data (the control paper, training test, test and examination results) derived from the LMS Moodle.

In the process of an experimental work, the pedagogical experiment method that took place in vivo was used. 20 lecturers agreed to take part in it. In the process of an experimental work, the testing results of 2283 students were processed. The results were generalized that led to the test improvement technology development.

In addition to the LMS Moodle (version 3.7), the specialized author computer program “Statistical Analysis of Test Results” and the SPSS statistical package (version 20) were also used in the research.

3 Results

3.1 The test task improvement technology

As a number of studies indicate, learning management systems are quite popular nowadays [16, 17]. And the MOODLE (Modular Object-Oriented Dynamic Learning Environment) LMS is considered to be the most effective and widespread [16]. The orientation to the MOODLE LMS environment is also due to the fact that this system is widely used for the learning process didactic support in universities. The control event results are exported to a spreadsheet document (.xlsx or .ods file) that contains:

- general information about the student;
- test duration (the test start and end time and the time spent);
- test score as a whole;
- answer results for each task (task types are Multiple choice, Matching, Calculated, Short answer, Numerical, Embedded answers, Drag and drop, etc.).

We developed a technology of the assessment means improvement, which is based on the educational measurement theory. There are a number of scientifically sound criteria for the quality of the test as a whole and for the individual test tasks from which we have chosen the item difficulty, discrimination, reliability and validity [10].

The item difficulty is associated with both the individual task and the test as a whole. For example, according to the item difficulty, the tasks are divided into the most difficult, the most successful, quite simple and very simple ones. The simplest and quite simple tasks should be at the beginning and in the end of the test, and the most difficult ones should be at the center of the test. The total test item difficulty is divided into 4 levels: very high test item difficulty, the test is not balanced; the test is balanced according to the item difficulty; the test item difficulty is sufficient; the test item difficulty is bad.

The index of discrimination means the task ability to differentiate students from the better to the worse ones [18]. High discrimination is considered to be an important indicator of a successful test task. The index value is in the range of [–1; 1] and the qualitative values may be as follows: the task is functioning quite satisfactorily; a small task correction is required; the task should be reviewed; the task should be deleted.

The reliability is considered as the test result stability degree during repeated measurements [10]. That is, the test is reliable if it provides high measurement accuracy and the results are resistant to external factors.

The test must be valid. It is a characteristic that reflects its ability to get the results corresponding to the

testing purpose [10].

In addition to the mentioned test quality criteria, you should also consider the time indicator: the correlation between performance and testing time. The time interval when the students made the least mistakes is determined in accordance with the testing data.

According to the pedagogical test development algorithm, the following stages are gradually carried out: the test task bank development; the testing for the task approbation purpose (the item difficulty and discrimination checking); the test forming and the second testing session conducting (the test item difficulty, reliability and validity checking); the standardization procedure implementation (the preparation of several parallel test variants, the testing time calculation) [19].

Also, after testing, important indicators that provide additional information about the test tasks are: point-biserial coefficient for each task, nominative correlation coefficients, factor and analysis of variance results [10].

The authors have developed a phased test task improvement technology: 1) the test task bank forming (LMS Moodle); 2) the probation testing using the bank tasks (LMS Moodle); 3) the discriminativity and item difficulty level determination after the probation testing ("Statistical Analysis of Test Results"); 4) based on the "Statistical Analysis of Test Results" recommendations, some test tasks are deleted from the bank, the rest are improved or remain unchanged; 5) the testing is carried out (LMS Moodle); 6) the test task item difficulty level is determined ("Statistical Analysis of Test Results"); 7) based on the "Statistical Analysis of Test Results" recommendations, the tasks are redistributed in the test; 8) the testing is carried out (LMS Moodle); 9) the test reliability and validity are checked ("Statistical Analysis of Test Results"); 10) the optimal testing time is determined ("Statistical Analysis of Test Results"); 11) based on the "Statistical Analysis of Test Results" recommendations, adjustments are made to the test, if necessary; 12) the calculation of correlation coefficients like the point-biserial and nominative one (SPSS); 13) based on the SPSS calculation results, the tasks that should be deleted are determined; 14) the factor analysis implementation (SPSS); 15) based on the SPSS calculation results, the tasks that are the most significant to get an objective assessment are determined, adjustments are made, if necessary; 16) the testing is carried out (LMS Moodle), and empirical data are accumulated; 17) the ANOVA implementation to compare the student test results over several years (SPSS); 18) based on the SPSS calculation results, the final decision is made on the test effectiveness.

The technology is represented in the model (Fig. 1).

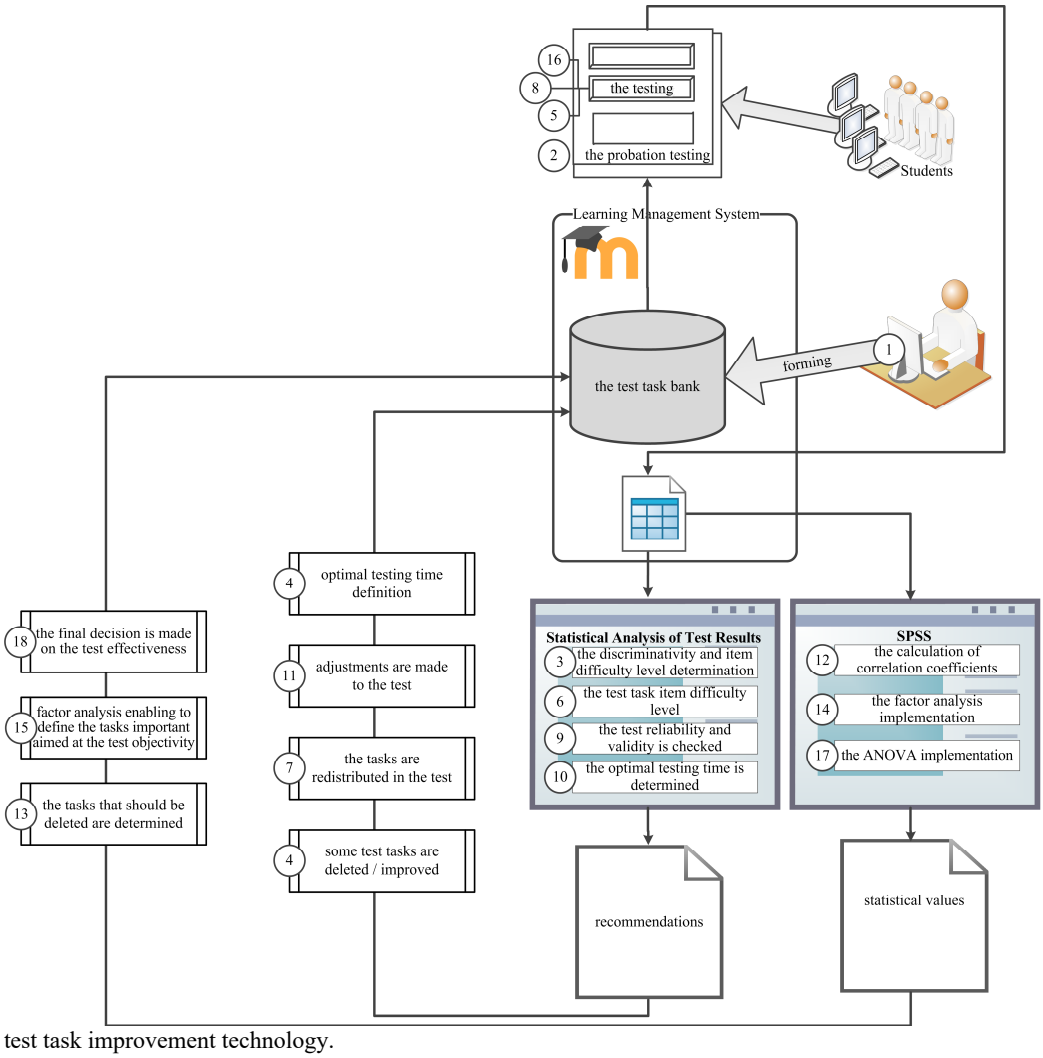

Fig. 1. The test task improvement technology.

3.2 Specialized computer program "Statistical Analysis of Test Results"

The "Statistical Analysis of Test Results" is a base for the introduced technology assessment means improvement, so let's take a look at this specialized computer program The C# programming language in Microsoft Visual Studio 2017 and the Windows Presentation Foundation technology have been selected for program implementation. When choosing the development means, we were guided by the following considerations: a convenient form designer and powerful means for working with arrays; the universal interface provides an integrated design and application component implementation.

The work with the Statistical analysis of students' test results software starts from the main window that is organized on the basis of pressing the buttons opening the corresponding system modules (Fig. 2).

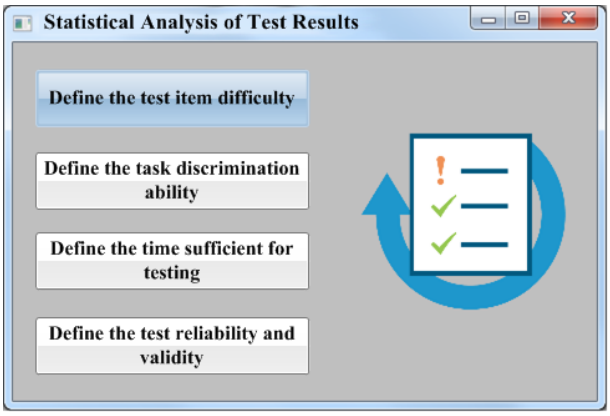

Fig. 2. The "Statistical Analysis of Test Results" software main window.

The clicking of the [Define the test item difficulty] button opens The Test item difficulty dialogue window (Fig. 3). The system is focused on the testing results in the LMS MOODLE, so it provides downloading files with these results (the [Download the file] button). You can get:
- the item difficulty of each task;
- the test item difficulty;
- the item difficulty of each task and the test item difficulty.

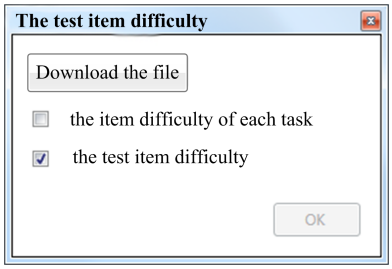

Fig. 3. The test item difficulty dialogue window

The results from the downloaded file are transferred to a dichotomous matrix, the initial test indicators are calculated: the ratios of correct and incorrect answers; if there is the item difficulty of each task checkbox, the variance is calculated; if there is the test item difficulty checkbox, the average task item difficulty level is calculated. After that, a window showing the test task and whole test item difficulty checking results is displayed. The numerical value of the item difficulty indicator and its level are derived for the test. The item difficulty level is determined for each test task.

The work of the task discrimination ability module (Fig. 4) helps determine the task discrimination ability of one test or recommendations on test tasks from the test task bank. That is why, the user can choose only one of the checkboxes after downloading the result file: the discrimination of the tests from the test task bank or the test discrimination.

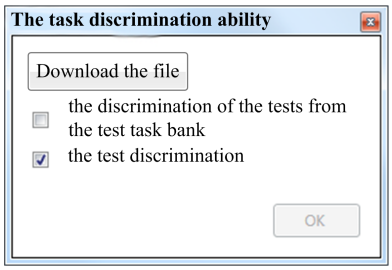

Fig. 4. The task discrimination ability dialogue window

It is envisaged that the results are displayed in groups after the discrimination checking of all the bank tasks: 1) at first, the tasks functioning satisfactorily are listed; 2) then, a list of those ones requiring a small correction is displayed; 3) next, there is a list of test tasks that should be reviewed; 4) at the end, there are the tasks that should be deleted. To do this, the test task bank statistics file is downloaded and the discrimination of the tests from the test task bank checkbox is put, the tasks are grouped according to discrimination indicators.

The test task discrimination checking derives recommendations for each test task. This is necessary when the test is generated by bypassing the test task bank. To do this, the index of discrimination is calculated for each task and a recommendation for each test task is derived according to the numerical value.

After clicking the [Define the test reliability and validity] button, the test reliability and validity dialogue window opens (Fig. 5).

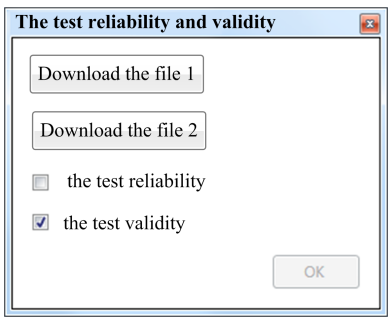

Fig. 5. The test reliability and validity dialogue window

After downloading two files, the user starts the process of calculating the main test indicators – reliability and validity. After pressing the [OK] button:

the program checks the test reliability checkbox and calculates the reliability indicator and derives a qualitative reliability characteristic; the program checks the test validity checkbox, calculates the validity indicator and derives a qualitative validity characteristic. These indicators can be obtained individually or together with two downloaded files.

A feature of the "Statistical Analysis of Test Results system is that it derives not numerical values but qualitative characteristics of the test and its tasks. This is convenient because the teacher does not need to analyze numerical values, define the item difficulty, discrimination, reliability and validity level and make decisions about the test and its tasks.

3.3 Test improvement technology implementation

The assessment means improvement technology used at Zaporizhzhya National University in the course of current, final and rectorial control, and also tested at Zaporizhzhya Regional Institute of Postgraduate Teacher Education during the special course and training "The basics of testology and student computer-based testing".

After the development of test tasks, the approbation testing is carried out. According to its results, the task item difficulty and discrimination are checked using the "Statistical Analysis of Test Results" software. The data help identify the tasks that need to be improved or deleted (Fig. 6).

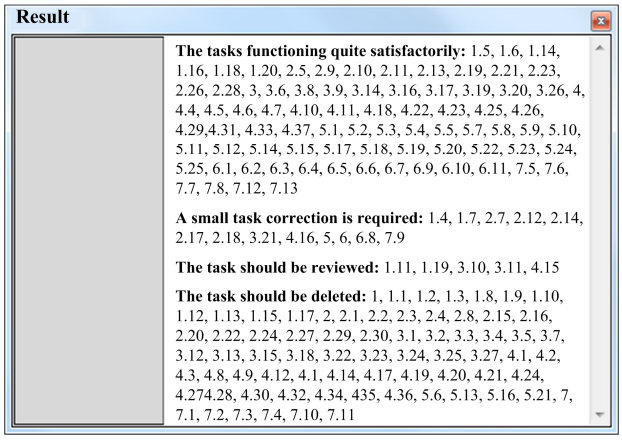

Fig. 6. The (bank) test task discrimination checking data

It should be noted that the process is sufficiently long and lasts all the time during which teachers use the testing. In addition, the knowledge and skill level of students of different study years is still different, so the system provides test task discrimination checking (Fig. 7).

According to the of educational measurement specialists' recommendations, the test should include 20% of the most difficult tasks, 20% of very simple and quite simple tasks, other tasks should be the most successful [10]. The test task distribution should be as follows: the simplest and quite simple ones should be at the beginning and in the end of the test, and the most difficult ones should be in the center of the test, unless the test mode involves the task randomization.

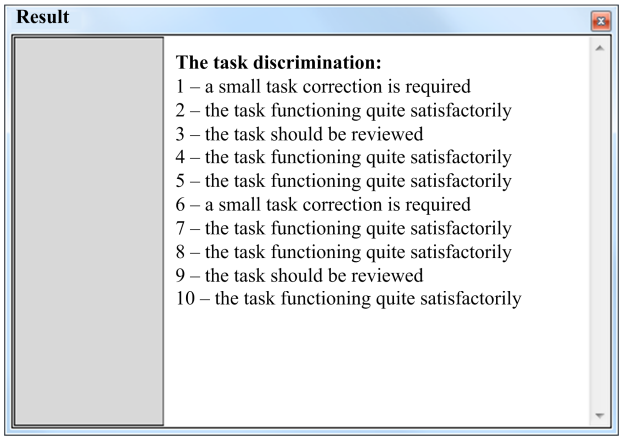

Fig. 7. The test task discrimination checking results

The Fig. 8 presents the test task item difficulty checking results. From these data it is clear that the test tasks are placed not in a balanced way there. After the task improvement and redistribution according to the item difficulty, an optimal distribution was obtained (Fig. 9). According to our observations, the simple ones were mostly the closed tasks (multiple choice and conformity) and the most difficult ones were the built-in answers.

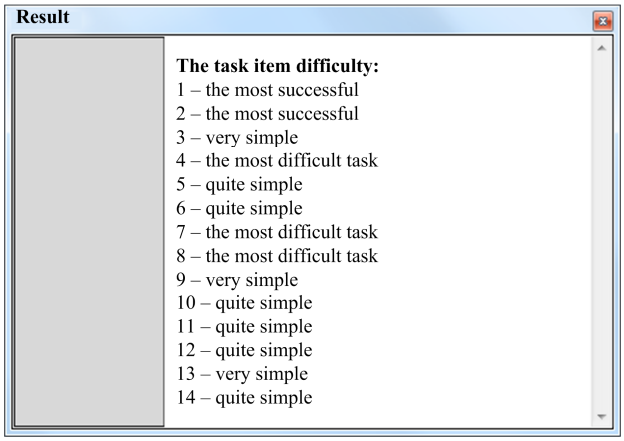

Fig. 8. The test task item difficulty checking results (version 1)

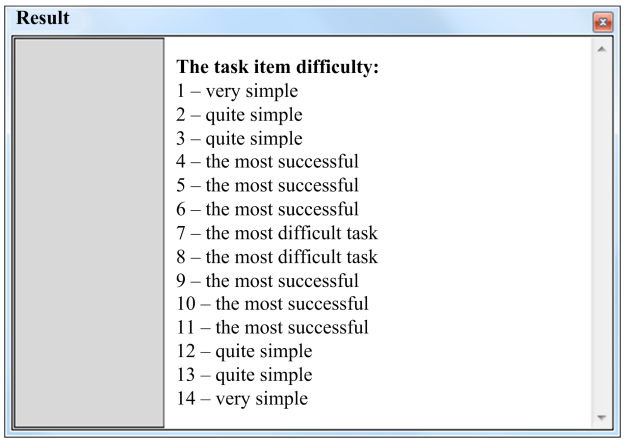

Fig. 9. The test task item difficulty checking results (version 2)

The item difficulty, reliability and validity indicators helping evaluate the test quality are calculated for the tests. The developed tests are repeatedly used in the higher education institution educational process, often the final control (credit or examination) is carried out with the help of them. There is also the practice of using a pilot test, through which students conduct the test preparation self-monitoring.

The results of any test are processed and a level of difficulty is obtained. The teacher can continue the task improvement, add more or less difficult tasks if the test item difficulty is bad, the test item difficulty is sufficient (Fig. 10) or the test is not balanced (Fig. 11).

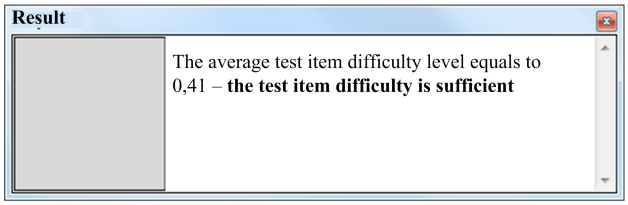

Fig. 10. The test item difficulty checking variants (version 1)

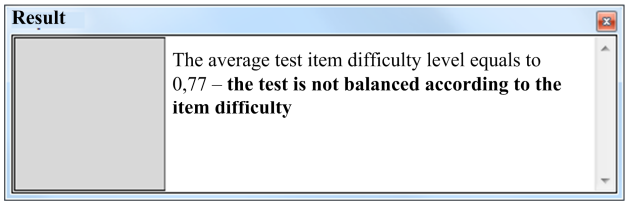

Fig. 11. The test item difficulty checking variants (version 2)

The reliability checking is performed according to two parallel testings (the pilot and control one), and the validity checking is also based on the control and final work results. The Fig. 12 and Fig. 13 show two sufficiently divergent variants of the reliability and validity test checking. An unsatisfactory test validity or reliability is a signal to the task change.

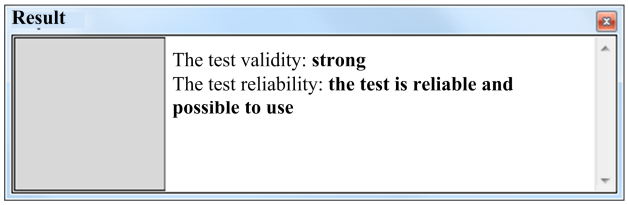

Fig. 12. The test reliability and validity checking variants (version 1)

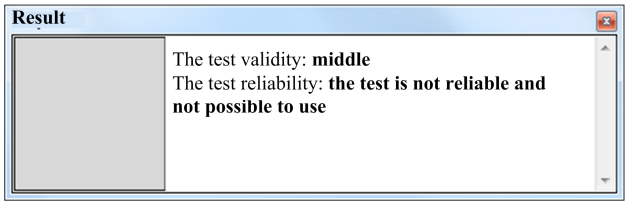

Fig. 13. The test reliability and validity checking variants (version 2)

As noted above, an important problem of testing is the time allotted for it. The disadvantages are both the insufficient amount of time and its excess. In this regard, the developed program defines the optimal time to pass the appropriate test according to the testing results (Fig. 14).

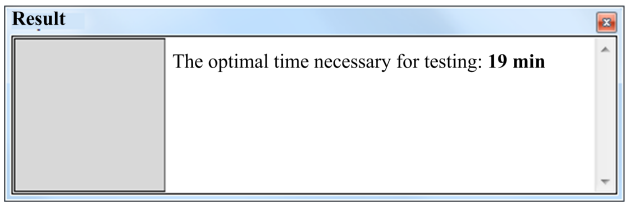

Fig. 14. The definition of the optimal time necessary for testing

The calculation of the point-biserial correlation for each task helped check the task differentiation (Table 1). Since all indicators are greater than 0,2, all the tasks differentiate students well.

Table 1. The calculated point-biserial correlations

Task	Test 1	Test 2
1	0,202	0,213
2	0,353	0,654
3	0,372	0,679
4	0,234	0,619
…	…	…
19	0,514	0,235
20	0,505	0,581

It was found in the process of obtaining complexity indicators that the closed tests (Multiple choice and Matching) are among the simplest ones according to the item difficulty. The point-biserial correlation also proved this.

A part of the lecturers does not go beyond the theoretical closed tasks (Multiple choice and Matching) when developing tests, therefore, the research of two tests from the same discipline was conducted by using a factor analysis (the same students took the test). One test included solely theoretical tasks, and another one open-ended tasks of different types in addition to the former ones. The first test included tasks identical to the second test tasks: the task 1_1 was identical to the task 2_1, the task 1_2 was identical to the task 2_5, the task 1_3 was identical to the task 2_4. The factor analysis results showed the following: the factor 1 (informativeness of 24,7%) included all the open tasks; the identical tasks were in the same factor (2, 3 or 4) in pairs. Therefore, open test tasks put a higher load into the test score.

The variance analysis results also proved that the test improvement factor inclusion contributed to a more adequate assessment. The score of students who were tested by improving means was lower than that the one of the groups that was tested by non-improving tasks. The test improvement factor had a significant impact on the assessment adequacy.

428 tests (37,7%) for different disciplines (higher mathematics, computer science, programming, pedagogy, economics) used to evaluate the students at Zaporizhzhya National University and to train teachers at Zaporizhzhya Regional Institute of Postgraduate Teacher Education were analyzed by using the presented technology. This program was used to check 1375 (32,9%) tests for item difficulty and discrimination that

in turn helped improve them. As a result, it was found that 63,7% of the test tasks functioned quite satisfactorily while others required a small correction according to the discrimination; 66,9% of the tasks had a sufficient test item difficulty level, and 31,1% of the tasks needed to be balanced according to the item difficulty (the item difficulty is very high or not sufficient); 82,3% of the tests were reliable; 74,9% of the tests showed high and medium validity levels.

Table 2. Factor structure of 10 tasks

Component matrix[a]				
task	Factor			
	1	2	3	4
1_1				,807
1_2		,903		
1_3			,833	
2_1				,891
2_2	,610			
2_3	,592			
2_4	,446			
2_5		,912		
2_6			,874	
2_7	,870			
Definition method: Principal component analysis.				
a. Defined components: 4				

4 Conclusions

So, the need to improve the future specialist training quality is based on the effective higher education system. It should not only create conditions, but also have reliable tools for the student knowledge level assessment.

The effective future specialist training system functioning depends largely on the perfection and quality of the assessment means, the most common of which are tests. Tests must meet the requirements for the item difficulty, discrimination, reliability and validity indicators. A study of the formulas used to make the calculations showed that a computer program could be an effective solution to the test quality checking problem. The paper presents a specialized computer program "Statistical Analysis of Test Results" that consists of four independent modules and derives the qualitative characteristics of the indicators involving the basis for making a decision on the need for test task improvement, as well as to define the optimal testing time. Fourthly, a special procedure to increase the test quality helping improve the means is needed. For this purpose, special indicators are applied: item difficulty, discrimination, reliability and validity. This procedure is presented in the form of a special technology that includes testing in the LMS MOODLE environment, calculating the main test quality indicators by using a specialized author program and statistical processing of empirical data with the help of the SPSS program environment. The results of the assessment means improvement program and technology approbation in the process of testing the applicants of the Zaporizhzhya National University and the postgraduate education system students proved their effectiveness.

The test improvement technology introduction has let make the tests transparent and objective. Such a test improvement will improve the future specialist training quality. Then it can be expected that in the future they will be able to think critically, generate creative ideas, make original decisions, strive to ensure the global environmental safety, economic prosperity, justice and equality.

It is possible to choose such developed program improvement directions as the test task distractor analysis, optimal the test length determination, the test task calibration for further research. It is also desirable to introduce a special course on educational measurements for students in pedagogical disciplines and practicing teachers.

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The use of digital learning tools in the teachers' professional activities to ensure sustainable development and democratization of education in European countries

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Abstract. The article deals with the revealing and analysis of the experience of the teachers' use of the digital tools in their professional activities in the European countries (Germany, Italy, Netherland, Denmark, Estonia, Croatia, Sweden, Finland, Macedonia, Norway and others). The online recourses ensuring the creation of the sustainable environment for teachers and students including key competencies areas: entrepreneurship, citizenship, civic education and STEM are revealed in the article. The presented recourses allow to creative use of digital technologies, identify teachers' and students' needs and finding technological answers, solve technical problems, identifying gaps in digital competence. Using the analysed resources teachers become aware of the need to improve and update their digital competence; ability to support others in developing their digital competence; search for opportunities for self-development and awareness of digital evolution that is proclaimed by the UN '2030 Agenda for Sustainable Development' adopted in 2015. The objective is to present the examples of the use of digital tools by European teachers, which are aimed at building the digital environment, developing the digital competence, and introducing innovations in the learning process. The critical use of presented experience in the comparative perspective can improve domestic teaching practice and teachers' professional development.

1 Introduction

Ensuring the sustainable development of education in the framework of modern reforms is an important task of the Ukrainian state. This task is of particular importance in the context of the European integration processes taking place in education, as well as in the context of democratization of society, and revision of the methods and content of education. ICT as a tool can be used by teacher, who is acting in the multicultural environment in European countries. Teacher plays an important role in these processes. The modern teacher has to follow the best European teaching practices, to keep up with the innovations not only in his country but also in Europe.

Sustainable Development Goals (SDGs) are outlined in the document 'Transforming our world: the 2030 Agenda for Sustainable Development' adopted by the General Assembly of the United Nations stated in 2015 [1]. This resolution identified 17 Sustainable Development Goals including education. Goal 4 is to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.

The *purpose of the article* is to analyse the current trends in the use of digital learning tools in teachers' professional development and practice from the perspective of SDGs, democratization and reformation processes in Ukraine and Europe in the comparative perspective, and to reveal the approaches to the development of the sustainable, democratic, multicultural digital environment in the educational institutions. *The research method* involved analysing the current research and practices including the domestic and European experience of the use of digital tools in teachers' activities as well as learning courses for their professional development as a way of introducing innovative technology into their practice.

2 Problem statements

The SDGs (Goal 4) states that by 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship. Also by 2030, substantially expand globally the number of scholarships for enrolment in higher education, including vocational training and information and communications technology, technical, engineering and scientific programmes [1]. In the same time the development of information and communication competence (digital competence) of teachers is considered, today, as an integral part of the reform of education system as a whole. The main purpose is to have an educated specialist in accordance with the requirements of the democratic, multicultural and information society who has the necessary knowledge, skills and information

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culture. The examples of the use of digital tools offered to the teachers in European countries are aimed at building the digital environment, developing the digital competence of the teacher and student, and introducing innovations in the learning process. Modern challenges of the European society require from educators to act in the multicultural digital environment, be prepared to propose their student's innovative ways of learning, communication, and investigation that will allow to form not only their digital skills but also prepare them to the labour market, entrepreneurship and citizenship.

The issues of development of digital literacy and competence as well as the use of and information and communication technologies in professional development are revealed in the number works, e.g. [2].

The article is aimed at the presentation of the different tools that teachers use across European countries under the common teaching aims. Comparative research of these tools lies in the fact that the authors try to show the diversity and common when using ICT for improving their digital learning strategies. Finally, the authors come to the proposals for the domestic in-service teacher training system on the improvement of the existing courses for teachers of different subjects regarding the development of their digital competence.

3 Results and discussion

According to the Conceptual Model of Digital Education presented by the Council of Europe considerable attention is given today to digital education, which is first and foremost about the opportunities not only to learn how to use digital resources, but also to have feedback on the use of ICT and the application of one's digital competence in work and study [3]. It is important that the learning tools are adaptable to the audience, and provide a feedback tool that better understands one's strengths and weaknesses, and that students and adults can find their own paths to success. Today the teacher should pay attention to the technological aspects of his/her digital competence, including:

- solving technical problems - the ability to identify technical problems in the operation of devices and use of digital environments, to be able to solve them (from troubleshooting to eliminating more significant difficulties);
- identifying needs and finding technological answers - based on needs analysis the ability to identify, evaluate, select, use digital tools and possible technological answers to solve them. Ability to customize digital environments for personal needs (e.g., accessibility);
- creative use of digital technologies - the ability to use digital tools and technologies to create knowledge, innovative processes and products; engage individually and collectively in cognitive activities to understand and solve conceptual problems and solve problematic situations in digital environments;
- identifying gaps in digital competence - the ability to be aware of the need to improve or update one's digital competence; ability to support others in developing their digital competence; search for opportunities for self-development and awareness of modern digital evolution [3].

The digital skills, digital competence, digital citizenship is the subject of attention by a number of international organizations. Among them is the World Economic Forum, started in 1971, which is an international organization of public-private cooperation as a non-profit fund. The Forum attracts leading political, business and other leaders of society to form global, regional professional programs. In particular, the Forum supports the efforts of many public and private sector organizations, international organizations, and academic institutions in developing the economies of the countries that are implementing modern reforms. Starting in 2016, the World Economic Forum focuses on digital competence and relevant citizen skills and support for digital learning strategies. According to the Digital Economy and Society Index 2019 (DESI), all EU countries have improved their digital performance, with countries such as Finland, Sweden, the Netherlands and Denmark having the highest rankings in DESI 2019 and being one of the world leaders in digitalization and are today the most developed in the field of ICT use by their citizens. These countries are followed by the United Kingdom, Luxembourg, Ireland, Estonia and Belgium [4]. And although the level of ICT development in these countries allows citizens to use digital tools and develop their competence, it should be noted that according to the above report, 43% of Europeans do not yet have basic digital skills, even though 81% of Europeans turn to online resources at least 2 times for a week. It should also be noted that the largest number of Internet users are young people (97% aged 16-24) and those with a high level of formal education (97%). Thus, the use of digital technologies in life and work is an important indicator of the education, progress and level of use of ICT systems in education in Europe. Digital citizenship is closely linked to digital citizenship, a strategy that is actively pursued internationally. Digital citizenship, as a concept, is nowadays widely used by the European and global community to determine how citizens identify themselves, using ICT skills and competences.

In view of the above mentioned issues, the experience of using digital tools by teachers to carry out professional activities in the experience of European countries should be distinguished.

The documents of the Council of Europe, the European Union, the UNESCO, the UN recognize Multicultural Education as a fundamental principle that directs educational activities of educational institutions of different countries to the mutual recognition and interaction of cultures.

The Multicultural Education strategy emerged in response to the exacerbation of ethnic, national, and religious conflicts in modern society as a result of significant migration processes between countries in different regions of the world. Multicultural competence and multicultural dimension in education with ICT play a special role in lifelong learning today.

Consider, for example, two learning tools that teachers use in their work to shape the multicultural competence for themselves. The Multicultural

Interdisciplinary Handbook was created as part of an international project during October 2009 – September 2011 with the financial support of the European Commission (Comenius program) [5]. The participating countries of the project were Austria, France, Germany, Italy, Poland, and Spain. The aim of the project was to create and distribute textbook, digital modules, a learning course for training future teachers of history and geography, and professional development of working teachers. The developed teaching materials help teachers to immerse themselves in the culture of other people through the study of geography and history, motivate them to study foreign languages. The handbook is presented online in six languages and can be used by all history and geography teachers interested in developing Multicultural Education. The digital modules are available free of charge in the form of video podcasts, content material (in HTML), standard training developments (in SCORM – IMS).

The multicultural experience of communicating with representatives of other countries and cultures is of great importance for the formation of multicultural competence. Therefore, one of the most effective means of forming multicultural competence is Culture Assimilator method [6].

The methods' goal is to teach a person to see different situations from the perspective of members of another's cultural group, to understand their vision of the world. The tasks of the cultural assimilator are the following: the acquisition of isomorphic attributions as the ways of interpretation of human behavior by representatives of foreign cultures; the experience of their emotional reactions in the circumstances of interethnic interactions and their correction; the formation of the tolerant behavior in a foreign cultural environment.

"Cultural Assimilators" is a training complex that includes: a brief description of situations where there is a problem of cultural adaptation or a problem related to cultural diversity between two interacting representatives of different cultures; four options for interpreting the behavior of the acting characters; explanations for each interpretation that involve discussing and determining the most appropriate answer.

Teachers can create and simulate problematic real-life situations for cultural assimilators using computer programs. Finnish scientist K. Korhonen has developed and implemented into the educational process of undergraduate students a "cultural assimilator" in the form of a web application called "The Same but Different" [7].

The analysis of educational scientific sources has made it possible to identify the following ICT tools that are widely used in the process of Multicultural Education: Web 2.0, virtual learning communities, educational electronic complexes, feature and educational films, thematic sites, online games, international educational online projects. Thus, ICT tools are today a new technological basis for the development of self-education skills, contribute to overcoming stereotypes, the formation of modern information culture and the required level of digital competence.

We can identify the main areas of use of digital learning tools by teachers in their professional activities, in particular for the formation of multicultural competence. Among them: distance courses in foreign languages and culture (OpenLearn platform: English, French, Gaelic, German, Italian, Welsh; Learn 48 Languages Online for Free: Spanish, Chinese, English & More; Study.com (Spain), Livemocha gives access to free lessons for 35 languages and offers communication with the of native language speakers from 190 countries; e-learning programs for the development of multicultural understanding and awareness (Finland); multicultural and media education through ICT (Portugal, Romania, Poland, Latvia); creation of a multicultural educational environment in schools using ICT (Ireland, Netherlands, Denmark, Finland, Iceland, Belgium, Italy, Sweden, Latvia, Portugal); implementation of multicultural education through multimedia learning (Denmark, Estonia, Slovakia); use of the media to promote multicultural understanding and overcoming stereotypes (Germany, Estonia, United Kingdom); use of an electronic multicultural interdisciplinary handbook by teachers of history and geography (Austria, France, Germany, Italy, Poland, Spain); use of electronic educational resources in the process of multicultural education (Austria); the use of virtual simulation training games that reproduce multicultural aspects of life (Bulgaria, Estonia) and others.

One of the actual problems is the constant self-development, professional development and development of the digital competence of the teacher without leaving his job.

In this regard, Massive Open Online Courses (MOOCs) are being actively introduced in 2008; the idea was suggested by Dave Cormier from University of Prince Edward [8].

The topics for the courses are selected by experts and tutors according to the needs of society and globalization processes in Education.

For example, as part of the European Schoolnet Academy project is a free MOOCs that includes theoretical material in the form of texts and video lectures, webinars, videos of teachers of European countries with stories and lessons to share their professional experience, instructions for the practical use of ICT in the professional activity of participants of a course, their communication on social networks through course questions and professional solutions, tests for each module of the course and the end result, such as a lesson plan or other ICT training course. Participation in these courses and analysis of their tasks and topics during 2017-2019 years gave us the opportunity to highlight the following important problems regarding the modernization of the educational process and the professional development of the teacher according to inquiry-based pedagogy:

- to provide career information to motivate students and present a variety of STEAM and ICT-related jobs and skills required ("Teaching ICT with Inquiry"; "The Networked Teacher – Teaching in the 21st Century"; "Games in Schools"; "Personalised Learning in Practice – are my students driving their own learning?"; "Yes I

can" – Empowering Student Learning"; "TeachUP Course: Collaborative Learning in Practice – are my students learning through collaboration?");
- to become familiar with innovative tools and approaches such as visual programming tools, unplugged activities, robotics, tinkering, and making and coding for all subjects ("EU Code Week - Deep Dive MOOC"; "The Networked Teacher – Teaching in the 21st Century"; "Games in Schools"; "Yes I can" – Empowering Student Learning"; "TeachUP Course: Collaborative Learning in Practice – are my students learning through collaboration?"; "Boosting Bioeconomy Knowledge in Schools"; "Social Media Literacy for Change");
- to learn about active learning, innovative uses of ICT and collaborative teaching and learning ("Teaching ICT with Inquiry"; "EU Code Week - Deep Dive MOOC "; "The Networked Teacher – Teaching in the 21st Century"; "Games in Schools"; "Yes I can" – Empowering Student Learning"; "TeachUP Course: Collaborative Learning in Practice – are my students learning through collaboration?"; "Boosting Bioeconomy Knowledge in Schools"; "Social Media Literacy for Change"; "Become the Next eSafety Champion").

In addition to suggestions on how to improve the effectiveness of teaching in the schools, these courses provide advice on the use of thematic portals and sites, training programs, computer games, and etc.

For example, "The Teaching ICT with Inquiry" course suggested using the Go-Lab ecosystem (https://www.golabz.eu/) to:
- students to conduct experiments in on-line laboratories in STEM fields, to participate in educational projects, in the implementation of which they need to use knowledge, skills and competences in the natural sciences, technologies, engineering, various fields of arts and mathematics;
- teachers to create and select didactic materials for teaching their subjects using the STEM approach, to share their pedagogical experience with colleagues from different countries of the world, etc.

Go-Lab ecosystem is projecting which creating since 2014. The Go-Lab initiative came about thanks to the successful Go-Lab project, which lasted from November 2012 to October 2016. The goal of the Go-Lab Initiative is to promote the use of online labs and applications for teaching and implementing research projects in schools. The Go-Lab Initiative provides a Go-Lab ecosystem for teachers where they can find various online labs and create their own learning spaces. The Go-Lab Initiative provides training for teachers across Europe on science education in schools and the use of the Go-Lab ecosystem. The Go-Lab initiative is currently funded by the Next-Lab project. The Go-Lab ecosystem consists of two main components. Go-Lab is a Sharing platform that provides hundreds of remote and virtual labs, as well as software or applications for query study. The Go-Lab platform enables teachers to create their own learning environments, combining labs, applications, and other resources for sharing with their students.

What is important about MOOCs is that the end result of each of these courses should be a personal training event developed by the course participant, such as a training project using the tools offered in the course. This result is evaluated using the peer-to-peer method.

It should be noted that the content of the courses is renewed every year, namely:
- new topics (e.g., the use of computer games to teach and teach different disciplines, training according to the needs of society, the use of new tools for monitoring, control and self-assessment of knowledge, skills and abilities of students and teachers);
- new tools for improve forms of learning (e.g., the use of new electronic platforms for STEAM projects in formal, non-formal, informal and inclusive learning; creation of computer-oriented environments, etc.);
- new lessons learned from teachers' experiences in implementing STEAM education in the schools (e.g., teaching STEAM projects, lessons on specific topics in STEAM fields, STEAM weeks, etc. using ICT);
- updated country reports on the use of ICT in support of STEAM education and analysis of the results of implementation of the STEAM approach in the schools (e.g., Science education now: a renewed pedagogy for the future of Europe: https://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf);
- new ideas are being generated to implement the STEAM approach in general education institutions (eg, to create websites that offer weeks of STEAM education in schools around the world: https://www.science-on-stage.eu/page/display/5/28/13343/coding-in-stem-education).

The experience of using digital technology teachers to gain knowledge in business education is interesting. This confirms the creation of European entrepreneurship education resources, such as the Virtual Entrepreneurship Education Handbook, which allows teachers from different countries to familiarize themselves with and use practical tools for primary, secondary and vocational education in their work.

Teachers from European countries are now successfully using the digital teaching HUB http://content.ee-hub.eu/. It brings together over 60 best practices in promoting entrepreneurship education in Europe on: national entrepreneurship education policy (Germany, Italy, Flanders, Denmark, Estonia, Croatia, Sweden, Finland, Macedonia, Norway, Denmark); teacher training (Enterprising School Program, Entrepreneurship360, Entrepreneurship Educators Program 3EP, 100 Mirrors, LIFE2 Project, STEP Model 2); partnerships (Cisco Networking Academy Networking, Combining Entrepreneurial Competence and STEM Industry Partnerships Skills, Accelerating the StartUp Ecosystem, YES – Finnish Regional Ecosystem Strategies to Implement National Strategies, Employee Volunteering – Added Value of Practical Entrepreneurial Programs, etc.); Entrepreneurship education ecosystem (integrates educational institutions of Spain, Serbia, Belgium, United Kingdom, Norway, Germany, Finland); tools (Measurement Tool for Enterprise Education

(MTEE), Entre Intention Tool: Measuring Impact at the Individual Level Entre Intention Tool: Measuring Impact at Individual Level, EntreComp: Entrepreneurial Competence Framework, etc.); Financial Education (Interaction between Entrepreneurship and Financial Education, Financial Education Programs from Primary to Secondary Levels, MoneyIQ and MoneyOnline, Financial Education Curricula, Your Finances, Your Future; I Can Manage My Money) and others.

In order to effectively integrate entrepreneurship education into the school education process, modern digital tools are being used to help create resources and projects involving representatives from different countries. This digital resource is the Entrepreneurial School http://theentrepreneurialschool.eu/ [9], co-financed by the European Commission, which includes 5 key objectives: teachers' continuing professional development and training; establishing quality supporting frameworks to measure best practice and to evaluate impact; development of appropriate support structures and activities; establishing networks between best practices; focusing on the initial education of teachers and the integration in the curriculum etc. The Entrepreneurial School project has trained over 4,000 teachers from 18 countries over the past three years, and has developed a Virtual Guide to Entrepreneurial Learning (http://www.tesguide.eu/default.aspx) [9, 10]. Focus groups from Denmark, Finland, Italy, Norway, Poland, Portugal, Slovakia and the United Kingdom worked on this development. The focus groups consisted of representatives of various education, business, government and citizenship institutions who were relevant to entrepreneurship education in their countries and played a key role in promoting entrepreneurship education.

Teachers in Europe are widely used by digital teaching platforms with open access by teachers to teaching resources. They are widely used in teacher training. For example, in the Netherlands, the following modern digital platforms should be distinguished: Teacher24 Learning Platform, created for educators from the Netherlands with the support of the Learning Cooperative and the National Educational Research Office (NRO) research organization, the Kennisnet Foundation, who work closely to support teachers' professional development in the use of ICT [Leraar24. URL: http://www.leraar24.nl (accessed: 12/24/2018)]. Launched in 2009, the Teacher24 platform (www.leraar24.nl) contains on-line teacher tools, including a variety of files and videos from a variety of teacher-created subjects [11].

On this platform, teachers can share their experiences with each other, offer their own techniques and discuss key issues, etc. Also, this resource hosts research in the field of pedagogy. In particular, this platform meets the new requirements of a competency-based approach supported by the professional teacher community. The central idea of the resource is the teacher's pedagogical, didactic and professional competence. The editorial board for scholarly publications teacher24.nl consists of teachers who make videos and write articles, edit and distribute these materials. For research-based articles, editors collaborate with researchers through the National Educational Research Administration (NRO) and the Kennisnet Foundation. By sharing knowledge and experience on teacher24.nl, teachers also communicate through social networks (Twitter or Facebook) that inspire each other to grow. LNE-Learning Network Education – an educational network for learning (http://www.leernetwerkeducatie.nl) supports online learning and acts as a communication platform between higher education institutions and practical training centers, through which the quality of hands-on learning is enhanced. Each student has the opportunity to create and develop their own profile in the learning environment. This allows increasing the quality control of practical training. The target group has a capacity of 15,000 users.

For the effective implementation of ICT in the national education system in the Netherlands, a Balance of Four model was developed (Netherlands, Vier In Balans). In order to have a positive pedagogical effect (benefits) of using ICT, it is necessary to ensure a balanced interaction of the four components: vision, experience, content and applications and content and infrastructure [11]. People as Educational Architects (Mensen Maken Scholen (https://www.pabo-inholland.nl)) is a simulation learning environment that offers educators the opportunity to create a virtual school and introduce themselves as a member of the school's team. the process in various roles, and "prevent" the students, creating problematic situations, and assist them in solving issues for further training to professional realities [12].

In general, public cloud services are widely depleted in Europe, offering many features designed specifically for a broad target audience. These are Google Apps for Education, Office 365 for Education, Dropbox, GSuite for Education, Apple Class kit / Classroom, and more. If publicly available cloud services lack the functionality required by the user or have problems with the terms of use, the institution may choose a private cloud.

Conclusions

The use of digital tools is recognized as appropriate by teachers of all subjects and school administrators. There is no doubt that modern pedagogical science requires a broader development of comparative pedagogical and empirical research in the field, highlighting important trends in the use of modern digital tools by teachers and providing guidance to decision makers. In this view it should be concluded that the use of digital tools and media by a teacher is closely linked to the digital competence, which requires the attention of the professional development system. A number of strategic documents have been developed by the international and European teaching community - a framework that relates to digital and civic competence as key competencies, an also the need to extensive use of digital tools in educational process. Ukraine has proclaimed a course on European integration of education, and educators today use educational guidelines and conceptual framework

documents, including the Framework of the Competencies for Democratic Culture, the Digital Competence Framework for Teachers, and others. There is a lack of the in-service teacher training introducing civic education through ICTs, as well as in-service teacher training.

Further research should be done in the sphere of developing approaches and organizational and pedagogical conditions for teacher training in digital competence and digital citizenship, improving the methods and forms of using digital learning tools to create a democratic and sustainable environment in teachers' practice. In this respect, particular attention should be paid to the experience of those countries where the use of ICT at school and the development of teachers' digital competency are proclaimed as a strategic objective of education. Work on the implementation of these tasks should be carried out systematically, when teacher training is supported and encouraged by school leaders and the education system as a whole. The use of digital tools is recognized as appropriate by teachers of all subjects and organizers of extracurricular activities, which, in turn, diversify learning activities. There is no doubt that modern pedagogical science requires a broader deployment of comparative-pedagogical and empirical research in the field, highlighting important trends in the use of modern digital tools by teachers, and taking into account the need for sustainable development of education, as defined in the Sustainable Development Goals (2015).

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Intelligent specialization as a promising strategy for the sustainable development of industrial regions of Ukraine (the case of Kryvyi Rih industrial region)

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Abstract. The paper discusses the basic principles of sustainable development as the dominant strategy for economic development, showcasing the features of its introduction in the major industrial regions of Ukraine. Substantiates the belief that the impact greening production useful in industrial regions, particularly in Kryvyi Rih, introduce European, including Polish experience intelligent (reasonable) specialization that takes into account the specificity of resources of the region and is based on the introduction of the latest smart technologies.

1 Introduction

The socio-economic situation in Ukraine is characterized by a complicated environmental legacy and hostilities in the East (2014-2020), which significantly hamper the country's sustainable economic development. Increasing concentrations of harmful substances in the atmosphere, destruction of forests, the disappearance of many species of fauna and flora, disturbance of ecosystems accompany the technogenic activity of the Ukrainian industrial complex and hostilities in the Donetsk industrial region. Moreover, the technological equipment of the country's great industrial enterprises is out of date, which does not meet the European environmental safety standards. This is especially true for large industrial regions, one of which is the Kryvyi Rih Iron and Metallurgical Region, one of the most powerful in Europe, producing about 80% of iron ore and 20% of metal, but with gross emissions of significant pollutants (dust, oxides) Kryvyi Rih is one of the first in Ukraine [1]. As Y. Maiakov, expert in geological and environmental studies GS "Environmental Council Kryvorizhzhya" said, Krivyi Rih and the entire region are under excessive environmental impact due to the multifaceted industrial areas that have a significant negative impact on the natural environment and pollute atmospheric air, groundwater, surface water, and soil. It results in human-made changes to natural landscapes, increasing the dose load on the population Rodney radionuclides, deteriorating health, and social indices [2].

An extremely critical ecological and economic situation in the Donetsk industrial region occurs, where Russian aggression has led to the loss of 50% of its industrial potential. Equipment for individual companies was exported to the territory of the Russian Federation or dismantled for scrap [3].

Therefore, it is worth acknowledging that the sustainable development goals, which have been recognized as strategic in the country for the last twenty years, have not been practically achieved, and that is why the Ukrainian society as a whole and the regional communities, in particular, have an urgent need to optimize their livelihoods, mainly production and consumption. That is why the problem of search and scientific substantiation of the newest concepts of economic development and ecological safety in the industrial regions of Ukraine, which can "breathe" into the strategy of sustainable development a new perspective idea, is actual.

The Sustainable Development Concept is a modern global trend for the last fifty years, it "aims at changing human-nature relationships to enhance economic growth and to create a coordinated global human survival strategy focused on conserving and restoring natural resources on a scale needed to bring communities back to scale of limits of economic capacity of the biosphere" [4].

Scientific research in the field of sustainable development is being carried out not only by economists but also by ecologists, political scientists, and sociologists since its implementation is connected with the most important spheres of human life – natural and social. Scientists considered ways and tools of transition to sustainable development, identified its indicators, formulated mechanisms of introduction of energy-saving and ecological safety systems, substantiated the levels of environmental impact on industrial enterprises on the environment.

The regional aspect of sustainable development is also reflected in the theoretical, methodological, legal, and scientific-methodological developments regarding its formation and implementation in the system of state and regional government through scientific research in this direction. Odesa, Kyiv, Dnipro, Lviv and Donetsk scientific schools represented them in the regions of Ukraine, but not so long ago noted by Ukrainian

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researchers, "scientific achievements have not been translated into administrative decisions at the state or regional levels. The results of scientific studies remain unused by management for the potential for sustainable development in the regions of Ukraine" [5].

Meanwhile, the modern period of economic development in European countries is focused on the search and implementation of new strategies, one of which is smart development, dominated by the union of science and business, the introduction of smart technologies, and intelligent (smart) specialization.

Therefore, *the purpose of this paper* is to analyze the features of the implementation of the sustainable development strategy in the industrial regions of Ukraine, in particular in the Kryvyi Rih industrial region and to substantiate the prospects and opportunities for the introduction of new strategies, namely smart specialization as a modern dominant of sustainable development.

2 Sustainable development as a world doctrine: the Ukrainian context

The issue of sustainability is one of the most studied not only in economics and ecology but also in environmental sociology, geography, and even ethics and culture. It is because the concept of sustainable or balanced development applies not only to environmental and economic aspects of economic development but also to virtually all other spheres of human life: social, cultural, domestic, medical, and other. It requires not only technological change in production technologies but also in value reorientations in the minds of the population, especially young people and those engaged in entrepreneurial activity or working in state structures. It is no coincidence that the Sustainable Development Challenge embraces at least two major ideas:

first, this development involves addressing economic, social, and environmental problems, namely "achieving a balance between the various factors that determine the overall standard of living"; and, secondly, "the present generation has a duty to the future generations to leave sufficient reserves of social, natural, and economic resources to enable them to secure a level of well-being no lower than what we have now" [6].

The term "sustainable development" was first formulated by prime minister of Norway Gro Harlem Brundtland, in a report entitled "Our Common Future", prepared for the United Nations and published by the International Commission on Environment and Development in 1987, defined it as "a development that meets the needs of today, but does not compromise the ability of future generations to meet their own needs" [7].

This definition clearly expressed concern for the future generation, which may inherit polluted air, depleted natural resources, and deforested landscapes as a result of the generation of the present. Moreover, Brundtland has compelled humanity not only to pay attention to its concern for the environment but also to listen to its message, which called for everyday ways to conserve the environment through balanced, rather than accelerated and destructive use by environmental entities. The answer to her message was the concept of sustainable (balanced, sustainable, eco-development) development.

The analytical work carried out by Ukrainian experts with the support of the United Nations Development Program in Ukraine and the Global Environment Facility in the framework of the project "Integration of Rio provisions into national policy of Ukraine" resulted in the development of the Sustainable Development Strategy of Ukraine until 2030 and the National Action Plan until 2020, which aims to Ukraine's fulfillment of international obligations and creation of real preconditions for Ukraine's full membership in the European Union, including the implementation of the EU-Ukraine Association Agreement [8].

An essential role in the implementation of the principles of sustainable development in Ukraine was also played by the National report "Socio-economic potential of sustainable development of Ukraine and its regions", which reveals the methodology of forming a system of indicators of the development of regional socio-economic systems as a fundamental prerequisite for sustainable development of Ukraine and the system of criteria for assessing its social and economic potential [9]. The preparation and publication of this document provided an impetus for the release of the Decree of the President of Ukraine "On the Strategy of Sustainable Development of Ukraine until 2020" January 12, 2015 № 5/2015 [10].

Ukrainian economist B. M. Danylyshyn defines sustainable development as "a system of relations of social production, which achieves the optimal balance between economic growth, the normalization of the quality of the natural environment, the growth of material and spiritual needs of the population" [11].

Therefore, to ensure balanced development is not a purely technical problem that requires new technical means or technologies. It is a problem of changing the format and nature of social relations, the reorientation of social and individual consciousness to reasonable needs, to a careful attitude to nature, to environments, and its existence. That is balanced development – a claim behind this development model, which also has an ethical sense, this "shift in value orientations of many people" [12]. This is a comprehensive development strategy for the near-century.

It is no coincidence that on September 15, 2017, the Government of Ukraine presented the National Sustainable Development Goals: Ukraine report, which presents the results of the adaptation of 17 global basic sustainable development goals, taking into account the specifics of national development in four areas: fair social development; sustainable economic growth and employment; effective management; ecological balance and sustainability building [13]. According to this Program, Ukraine's public vision for 2030 encompasses such benchmarks as: improving the well-being and health of the population through innovative development of an economy based on sustainable use of natural resources; changes in the structure of exports that shift from raw materials and primary processing products to high value added products and services; economic growth on the green economy model; reduction of energy intensity of

gross domestic product due to energy saving measures and implementation of energy efficient practices; a steady increase in the share of green energy production, displacing, above all, traditional technologies, which will significantly reduce greenhouse gas emissions into the atmosphere [13]. These benchmarks should be considered simultaneously as indicators of the implementation of a sustainable development strategy.

Of course, the achievement of these sustainable development goals in Ukraine should contribute to improving the quality of life of the population without harming the environment and increasing life expectancy. However, the environmental situation in modern Ukraine is hugely complex, which significantly hinders the implementation of these ideas. Eight years ago, the head of the Ukrainian Ecological League, T. Tymoczko, noted that there are at least eight acute environmental problems in Ukraine that make it impossible for a stable and optimized development of the country, namely: poor quality water (80% of water samples show that its quality does not meet the requirements of the state standards); polluted air (more than 6 million tons of pollutants and carbon dioxide are released into the atmosphere annually); degradation of land resources (more than 35% of agricultural land has undergone erosion; 2.4 million hectares of acid soils have increased over the last 15 years due to fertilizers; nearly 40% of Ukraine's total land resources belong to contaminated lands); forest destruction (timber exports from Ukraine are 2.5 times higher than imports; the area of forests affected by pests and diseases is continually increasing); dangerous geological processes (41-43% of the country's GDP related to the extraction and processing of mineral resources concentrated in the mining regions of Donbass, Kryvbas, Carpathian region, the ecology of these regions suffers not so much from intensive extraction, unprofitable and produced mines and quarries); municipal waste (there are about 800 official landfills in the country, with a total amount of waste in excess of 35 billion tons); objects of military activity, of which 90% are morally and physically obsolete and operate with significant congestion); Chornobyl disaster (total activity of radionuclides beyond the 4 Chornobyl NPP units on April 26, 1986 and in the days following the accident, exceeded 300 million Curie, leading to radioactive contamination of more than 145 thousand square kilometers in Ukraine, Belarus and Russia) [14].

Is there any reason to argue that the concept of sustainable development has recently become actively implemented in large industrial regions of Ukraine? Are there any positive results? What are the blockers for this process?

3 Realization of the Sustainable Development Goals in the Industrial Regions of Ukraine

Today's economy of Ukraine can be attributed mainly to raw materials, where the most developed are iron ore and metallurgical industries. The main areas of the coal, iron ore, and metallurgical industries in Ukraine are the Donetsk, Dnipro, and Azov regions. The largest producer of steel and rolled products is Dnieper Metallurgical Region, formed based on its own iron ore (Kryvyi Rih, Kremenchuk, Kerch, Belozerskoe deposits), manganese ore (Nikopol and Velykotokmatske) flux and limestone, and which produces 95% iron and 100% manganese ore, about 50% iron, steel and rolled metal, as well as 66% steel pipes and 83% ferroalloys [15].

The core of the Dnieper Metallurgical Region is the mining and metallurgical complex of Kryvorizhzhya (one of the primary budgetary formers of Ukraine, which includes: "ArcelorMittal Kryvyi Rih" – the largest enterprise of the mining and metallurgical complex of Ukraine with a full-cast iron mill, enterprises of underground mining of iron ore, coke-chemical production. The activity of ArcelorMittal Kryvyi Rih is supported by numerous mining equipment factories and regional industrial enterprises and research institutions. The differentiators of the complex include: mass scaling, enterprise occupies large areas, extraction of minerals from the depth, terrific environmental concerns, pressure on the environment [16].

As noted by H. H. Gubin and G. V. Gubin, as a result of mining and processing activities in Kryvbas, became "large-scale disturbance of the earth's crust and development of technogenic exogenous processes such as landslides, dips, subsidence of soil, disturbance of the foundations of buildings, as well as geotectonic processes – movement of blocks the crust in the horizontal direction 3-10 mm/year, which are fixed, in the vertical direction – 2-5 mm/year" [17]. Besides, industrial production leads to the pollution of land, water, and air basins with toxic metals of anthropogenic origin, the most dangerous of which are iron, chromium, zinc, mercury, lead, cadmium, and others. These metals, accumulating in soils in too large volumes, contaminate them and lead to chemical changes, which harms human health, reducing their natural immunity, and therefore the average life expectancy [18]. It means that in the ecological environment of industrial regions irreversible processes occur, which disturb the natural and social equilibrium, and gradually lead to the destruction of the ecosystem and the Earth's crust, and also lead to socio-demographic changes in the social structure of the regional society.

Following the goals that are correlated with the goals of the sustainable world development, which were approved at the UN Summit in 2015, the management of modern Ukrainian enterprises, in particular, Kryvyi Rih, was forced to adjust their activities to technological, environmental, and social changes, which met the set goals. However, often these are just imitations of change since behind the scenes of minor technological improvements are often at the heart of the activities of industrial enterprises outdated technology or equipment.

Undoubtedly, one of the leading indicators of its implementation is the ecological status, since it is, on the one hand, the result of industrial activity, and on the other - the cause of the health and morbidity of urban residents, which also testifies to the results of the implementation of environmental protection programs.

According to the State Statistics Service, the environmental situation in Ukraine remains rather

complicated. Thus, emissions of pollutants and greenhouse gases into atmospheric air from stationary sources of pollution in 2018 amounted to 2508, 3 thousand tons [19]. It means that each resident of Ukraine in 2017-2018 had about 60.8 kg of pollutant emissions. In terms of territorial area, there are about 4.5 tons of air pollutants per square kilometer of the country's territory. It is in Donetsk and Dnipropetrovsk regions that these figures have significantly exceeded the national average. Thus, in the Donetsk region, emissions per one square kilometer were 6.6 times higher, and for one person three times higher, in Dnipropetrovsk region (in particular the city of Kryvyi Rih) – 4.6 and 3.3 times respectively [20].

According to the information of industrial enterprises, emissions of pollutants into the atmospheric air of the city of Kryvyi Rih do not decrease, but on the contrary – increase. Thus, for the nine months of 2019, they amounted to more than 210 thousand tons, which is 10% more than in the same period last year, and the volume of industrial waste generation – 178.2 million tons, which compared to the same period of 2018 increased by 3.7%. The primary air pollutants are the enterprises of PJSC "Arcelor Mittal Kryviy Rih", LLC "Metinvest-KRMZ" and PJSC "INGZK" [21].

How catastrophic is characterized by experts in the ecological and economic situation in the Donetsk region? By the beginning of the military conflict, there were 4 240 potentially dangerous sites in the Donbas, and by the end of 2018, 176 had been identified, 99 of which were located in uncontrolled territory, 36 mines flooded and were not recoverable; uncontrolled air pollution, use of powerful ammunition, disturbance of terrain and soil cover, chemical contamination of soil with heavy metals, petroleum products and other toxic substances leading to the destruction of entire natural ecosystems are a serious danger [22].

As a result of the military conflict in the Donbas, ecosystems in at least 530 thousand hectares have been destroyed, including in 18 nature reserves with a total area of 80 thousand hectares. Also, 150,000 hectares of forest were affected by numerous fires in the area adjacent to the war zone [23].

As a positive result, it should be noted that in Kryvyi Rih region operates urban programs to address the environmental problems of Kryvbas and the improvement of the environment for 2016-2025. The program aims to focus on actions of state authorities, local self-government and their executive bodies, organizations, institutions, and enterprises of the city of all forms of ownership for the implementation of priority areas of activity in the field of effective environmental management, compliance with environmental safety and environmental protection, educational activities and environmental awareness [24].

The largest metallurgical enterprise of Kryvyi Rih "ArcelorMittal Kryvyi Rih" for 2006–2018 invested UAH 6.1 billion in environmental protection measures and eco-modernization. Thus, in 2017, the company donated 850 million USD, and in 2018 – more than 5 00 million UAH, in 2019 – about 500 million USD. At the same time, over the next five years, the capital investment of the plant will amount to $ 1.8 billion, in particular in 2019 – about $ 300 million. The total investment of the industrial group "MetInvest" in environmental projects and 2014-2018 amounted to more than $ 1 2 billion, particularly in the 2018 year – $ 92 million. In the first half of 2019, direct investments in environmental activities have increased by 16% of equations with the same period last year – to $ 163 million [25].

However, the efforts mentioned above to address environmental problems do not yet produce the desired result. Air pollution, low water status significantly worsen the health of the inhabitants of the industrial regions. Thus, the incidence in Kryvyi Rih, including cancer, is steadily increasing. As of the end of 2019, 18.5 thousand patients with or suffering from malignant neoplasms are registered at the Kryvyi Rih City Oncology Center [26]. For 2019, 1878 were registered in Kryvyi Rih, who first became ill this year, and according to statistics annually in Ukraine, more than 160 thousand people know that they have cancer [27], so it turns out that every tenth of them is a resident of Kryvyi Rih.

In the Donetsk region, particularly in the war zone, the incidence of pulmonary tuberculosis and acute intestinal disorders has increased significantly, the Ministry of Health of Ukraine draws attention to it. Experts note that infectious diseases are not recorded, but complications can occur due to the destruction of housing and infrastructure, shortages of drinking water and food, lack of proper conditions for compliance with personal hygiene rules [28].

Therefore, despite urban and entrepreneurial conservation efforts and programs, the environmental situation as an indicator of sustainable development in the industrial regions of Ukraine remains dangerous and requires urgent effective action to improve.

4 Intelligent (reasonable) specialization as a new promising strategy for sustainable development of industrial regions

Generalization of the results of theoretical studies on conceptual approaches to sustainable development indicates certain advantages of its environmental component or combination of economic and environmental with particular neglect of the social component. For some time, in particular regarding the prospects of development of the Kryvorizhzhya mining and metallurgical complex, sustainable development has often been considered in the context of stable quantitative growth of raw materials and products, taking into account technological features and adverse effects of cyclically recurring demand for metallurgical products on world markets, environmental safety requirements. However, the use of social resources in achieving the goals of sustainable development and the leverage of social capital was underestimated [29].

Therefore, there is an urgent need to implement new sustainable development strategies based on the use of social and intellectual resources. One of them is the strategy of smart specialization, which is one of the priorities of smart development, which has been actively implemented since 2014, for example, in Poland. Its main

idea is the consensus of science and business, building a market economy based on knowledge, and the introduction of innovative and smart technologies [30].

The main principles of the Intelligent Specialization Strategy, according to Anna Grądziel, are: 1) the creation of a research and innovation sphere of adequate scope, which will allow a large number of organizations to compete with each other in the European Research Area (ERA12), which has an integrated and transnational in nature and allows for free flow of resources; 2) openness and focus on those areas of science and innovation that make up the socio-economic conditions and resources of the region; 3) the presence of so-called general purpose technologies (GPTs) that can serve as additional, but not final, conditions for development; 4) a creative process based on the potential of the region's development, not on an arbitrary decision of the state government [31].

Intelligent (reasonable**,** smart) specialization is impossible without the use of artificial intelligence. S. Russell, P. Norwig rightly paid attention to the development of a specialized multi-level expert system that, by analyzing the content of the information base (which in this case becomes the "knowledge base") by the method of "benchmarking", will be able to identify situations similar to the current ones that were previously, seek management decisions, evaluate and compare their moderation and effectiveness, and generate guidance on any issue [32].

That is, we are talking about the creation at the industrial enterprises and in the industrial regions of such a computer system, which according to E. Timofeev, will be able to assume a number of functions, i.e. to provide multifunctionality of production processes to be able to: identify the most "bottlenecks" at the moment; to predict the condition of the object in the near and long term (condition of equipment wear, depletion of sludge volumes, changing demand for products, investment climate, etc.); to develop recommendations for the development of reconstruction projects, both the whole complex of objects and individual enterprises; to provide advisory assistance in the implementation of specific projects; control the progress of project implementation [16].

According to the researcher, this system must have specific properties, namely accessible the modification of knowledge base, modularity of building a knowledge base and the inference mechanism, high versatility, and security of interface, activity system to update information for the knowledge base. The system should have a mechanism for making probabilistic predictive calculations. Special measures should be taken when designing a database where confidential information can be stored [16].

As noted by M. P. Sagaydak and N. K. Lavrenov, "The players in the mining and metallurgical industry must take on the challenges they face and adapt to new business models of their activities aimed at developing differentiation, stability, and profitability in the value chain. It is important to use digital technologies to solve these problems; however, only some of the metallurgical enterprises have made the necessary changes and realized the important benefits" [33].

Metallurgical enterprises of Ukraine, albeit slowly but still, have begun the process of sincere cooperation of business with scientists with the aim of accelerated modernization and introduction of digital technologies, which is an indicator of intelligent specialization. It is partly due to the Ukrainian steelmakers' Worldsteel rating of the World Steel Association is ranked 11th with an index of 1.9 million tonnes of steel melted (by 2014 Ukraine was in the top ten list and dropped to 13th place during the Donbas war), and only in August 2019 did it further improve its position [34].

The leader of the metallurgical industry of Ukraine and the largest foreign investor in the country JSC "ArcelorMittal Kryviy Rih" proclaimed that it sees its production philosophy to "produce safe environmental steel and therefore in all its operations: from mining of iron ore and steel production products to consumers, guided by a responsible attitude to business, principles of ethics and transparent management" [35]. In 2019 at the plant started hot testing of the reconstructed state-250-4, power which will increase from 800 000 to 1.04 million tons per year, and emissions will be reduced by 131 tons. The cost of the renovation was $ 50 million. In the next five years, ArcelorMittal plans to direct $ 1.8 billion in production development. Among its major projects is the construction of a pellet factory. It will allow the abandonment of obsolete agglomerate production and reduce hazardous emissions by 50-55% [34].

"Smart" technology "Mobile traffic light" was introduced at the metallurgical plant "Zaporizhstal" for operational monitoring of production processes: the shop hot-rolled thin sheet in a pilot mode with 2 000 sensors that can read 130 000 parameters of the equipment. The program makes it possible to make a prompt decision on the timely completion of the necessary repair works : the percentage of wear, frequency of replacement of parts, service life, speed of defect development, etc. is calculated , it is envisaged to collect and record in a single electronic database the condition of equipment in all shops. About the same system has been operating at the Interpipe Steel plant (Dnipro) since 2016 – this is the Smart module EAM for the maintenance and repair of equipment, which contains all information about the essential equipment of the plant, including drawings, repair maps of each site. As a result, the number of accidents at work decreased from 2% to 0.3%, the volume of defective products at the equipment emergency stop decreased all the time, the stock of spare parts in the warehouse decreased by 10%, and the overall efficiency of the equipment increased by 10-15%. Now Interpipe is introducing another system – Smart.Factory is a cross-cutting and production planning project. The system is built based on Industrial Internet of Things (IoT) technology – information about each product (e.g., melting point, steel grade, order number, etc.) is stored in a single database. Interpipe tests this system for pipe production, but it can be adapted to any enterprise. Moreover, in the near future, such modules will appear at other metallurgical plants [34].

Scientists have long been discussing fundamentally new technology, namely, the production of iron ore and metal using hydrogen. In some places, this technology is already used for ore enrichment, but it is not in a hurry to introduce it at Ukrainian plants because of its high cost.

Therefore, it should be emphasized that the enterprises of the industrial regions of Ukraine, including Kryvyi Rih in the last years, have started the modernization process, which uses the components of intelligent specialization, but this is not enough. Tactically, they are affected by socio-environmental problems because of the need to respond to changes in consumer needs that reflect their concerns about the consequences of their industrial activities. However, in the long-term plans, the desire for sustainable development requires fundamental changes in the management paradigm, which is embedded in the mission of enterprises and which will ensure the full implementation of smart specialization.

Today, the goals of modern Ukrainian enterprises, based on the concept of sustainable development, combine environmental concerns with stimulating and encouraging consumers to increase profits and therefore view resources as an endless source of raw materials. However, it is worthwhile to change management approaches based on the fact that the new strategy of smart specialization will help to form new intelligent thinking, reasonable needs, and therefore change the structure of consumption and balance natural processes.

Within the framework of smart specialization, successful operation is ensured for enterprises that will apply long-term, environmentally friendly processes, introduce innovative technologies and products that have competitive advantages. Intellectual specialization itself needs to perceive sustainable development as a coherent philosophy, where environmental problems and responsibility for them are fully integrated into the life cycle of not only products but the entire system of economic activity. Specialized distribution channels are laid to work with niche consumers. The mission of enterprises must be developed based on sound environmental awareness [36].

There is no doubt that the introduction of the concept of smart specialization meets the needs and capabilities of the Kryvyi Rih region, as it has sufficient scientific, human, natural, and technological capital and potential for it. However, for this, it is necessary first of all to create a positive image of the region in the eyes of foreign investors through the development of environmental marketing. According to O. V. Latysheva, environmental marketing, which is formed on the principles of social and ethical marketing, aims to resolve the contradictions between the production and preservation of the environment [37]. Analyzing the attitude of leading foreign firms and companies to the environmental, and therefore social consequences of their activities, the researcher summarizes five main reasons for the importance of environmental marketing, in particular: considering it as an opportunity to achieve strategic goals; enhancing the moral obligations of economic entities to be more socially responsible to society; governmental control over the responsibility of enterprises, firms, companies for their activities; the influence of environmental actions of competing firms on environmental marketing policies and changes in the attitude of economic agents to the environment under the influence of cost factors related to pollution or scarcity of resources [37].

Secondly, as V. Vasylenko rightly points out, remote sensing of the earth - the latest method of environmental monitoring, which is the most accessible method of obtaining reliable information about the state of the environment in large territories due to the large amount of open data and free software for their processing, needs to be introduced and has a huge range of applications: ecology, construction, site planning, etc. [38]. It is worth agreeing with the researcher's view that in order to intensify the use of such monitoring methods, it is necessary to bring geospatial information used in Ukraine to the level of international standards, first of all by implementing the INSPIRE directive, which establishes general rules for the creation of geospatial and information infrastructure and enhances the qualification of users public information, especially at the state level.

5 Conclusions

Thus, sustainable development is a global economic and socio-environmental strategy, the main idea of which is to understand the need for change not only in the activities of industrial enterprises but also in the public consciousness of people and the culture of using natural resources. The focus of humanity is on the holistic and integrated priorities of the relationship between the economy, the environment, and society; physical stability of processes, their social acceptability; globality, not specific urgent challenges. At the same time, socio-environmental strategies are calculated not only for the long term but for an unlimited period when environmental care is considered not as a benefit to society but as an intrinsic, real, actual value.

At the same time, the analysis of the implementation of sustainable development strategies in Ukraine, in particular in large industrial regions, for example, in the Kryvyi Rih iron ore basin and the Donetsk industrial region, shows that there are many unresolved social and environmental problems.

Therefore, the *novelty of the scientific study* of the implementation of the strategy of sustainable development in industrial regions of Ukraine and opportunities for the introduction of smart specialization is as follows: firstly, it is found that significant positive changes in the environmental and socio-economic status of regions did not occur during its implementation period; secondly, the reasons for the lack of effective implementation of the sustainable development concept have been identified, yes which include the following: ineffective management of industrial regions; insufficiency innovation-investment component of sustainable development and its implementation; loss and / or ineffective recovery scientific-industrial relations between scientific institutes and business structures; absence sufficient and up-to-date government support for sustainable development through appropriate financial

and programmatic support resources; hostilities in eastern Ukraine; the unformed ecological paradigm of education, and therefore the ecological one the consciousness and culture of the population of the industrial regions, in particular the youth; thirdly, based on an analysis of Polish experience, it is justified that an effective strategy that can give a new impetus to activate sustainable development in the industrial regions of Ukraine, is the concept of intelligent regional specialization, which envisages deepening of cooperation of scientists and entrepreneurs; development and implementation of a set of new environmental standards for production; the development of innovative, in particular digital technologies that enable the efficient use of human and natural resources; improving the management paradigm; introduction of systematic environmental monitoring; division of responsibilities between authorities and business through the development of cooperation; formation of new ecological thinking and reasonable culture of consumption in society at the expense of educational activity and creative activity of young scientists and scientists.

Therefore, a promising area of research for the sustainable development of industrial regions is the elucidation of the specifics and factors that will accelerate the introduction of intelligent specialization in the production processes of mining and metallurgical production.

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Education individualization by means of artificial neural networks

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Abstract. This paper examines the issues related to the implementation of an educational process based on modern information technologies use. The main purpose of it is to achieve a significant level of individualization of the educational process, taking into account the individual characteristics and capabilities of each participant of the process. The implementation of the approach became possible at using elements of the theory of artificial neural networks in the educational process. Based on the network, it is possible to build a model of the educational process; it will significantly increase the control of the teacher on the educational process. Moreover, this network can adapt to a specific education task, the individual characteristics of the student and teacher. The mathematical model of the educational process using modern information technologies and neural networks is constructed. Their use is based on the developed criteria of successful execution of various stages of the educational process. Such criteria are designed for both the student and the teacher. The characteristic of participant's activity of the educational process is considered in the work. A numerical interpretation of this concept is proposed.

1 Introduction

Modern pedagogical technologies rely on the latest educational informational means. In particular, computer and robotics training requires a teacher and student to use basic knowledge in Physics, Mathematics, Programming, and Engineering. The training system of future teachers of natural and mathematical disciplines aims to develop the skills of engineering thinking, the use of technologies to solve problems, to familiarize them with the basic concepts and information in mathematical modeling and object construction.

The education process is a communication system, and it can be described as an artificial neural network of influences. It has a function with many variables at the input and a fixed result at the output. For such a representation it is necessary to formalize the educational process in a certain way, to construct its mathematical model, which will take into account all the steps necessary to achieve the purpose of the educational study. Recently, there has been a significant increase in using elements of the theory of artificial neural networks in the educational process. This interest is specified by the ability of such networks to respond quickly to changing conditions of the education process, adapt to these changes, analyze them and find the optimal parameters.

Modern educational needs are search, development and application of innovative models of organization of the educational process [1, 2, 3]. In this regard, there is an urgent need to introduce the elements of education in the teacher training system, to introduce students to the elements of programming, design, mathematical modeling, and more. The system, in this case, means the set of elements that interact and communicate with each other and create the appropriate integrity, organized to achieve one or more goals.

Questions of constructing models of the training system by means of neural networks were analyzed by O. D. Humennyi [6], A. E. Kiv [14], V. S. Kruglyk [2], O. M. Markova [12], V. V. Osadchyi [16], V. N. Soloviev [15], R. V. Streltsov [5], I. O. Teplytskyi [13] and others. Possibilities of neural networks as a component of students' distance education system were considered by P. I. Fedoruk [4]. The artificial intelligence in the system is responsible for knowledge control. It allows to determine the level of educational achievements of students and to model the personal education trajectory, selecting the appropriate training modules. R. V. Streltsov and L. V. Slavinskaya [5] developed a computer-based education system using neural networks to optimize interaction between all participants in the education process. O. D. Humennyi proposed the model for the use of the Kosco neural network for the concept of designing Smart complexes of subjects [6]. In their works V. V. Osadchyi, V. S. Kruglyk and D. O. Bukreev use a neural network training mechanism to determine the likelihood of entrants to higher education institutions [7, 17]. In [8], the dependences of student performance (good and excellent grades) on the number of control nodes per semester in various academic subjects (analytical

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geometry, mathematical analysis, and physics) are constructed. In [9], a model of optimal quantitatively grounded system of training of future physics teachers based on the relative importance of the education goals. However, little attention has been paid to constructing a neural network model based on numerical characteristics of the control, analysis, and correction to individualize of education.

The study of disciplines of the natural mathematical cycle, raises the question of strengthening the individual approach in the study of these disciplines, taking into account the individual characteristics of the student and the teacher. However, enhancing of education individualization leads to a significant increase in educational work, sometimes poorly linked to the education content. The application of artificial neural networks to the educational process, which, combined with modern computer technology, can significantly simplify this process and enhancing the level of education individualization. The use of artificial neural networks in the education process implies, first of all, that the whole education process, or at least its main elements, should be presented in digital form. For the disciplines of the natural mathematical cycle it is a feasible task. However, the educational process of a large number of disciplines is poorly formalized, and sometimes it is not at all conceivable as a sequence of particular pedagogical influences that can be measured or estimate by numerical values. So, we propose a method of elementary tasks, which, in our opinion, can greatly facilitate the formalization of the educational process of a considerable number of disciplines. Moreover, using this method, it becomes possible to apply the elements of artificial neural network theory in the educational process. The main purpose of this work is to establish numerical characteristics that are amenable to algorithmization, control, analysis and correction by means of neural networks, and provide a high level of individualization of training.

2 The method of elementary tasks

The elementary tasks method is based on the concept of an elementary task. Here is a description of this concept.

Let's consider educational (pedagogical, educational and other) task. Let us denote this task by Z. Suppose that the task Z can be fulfilled only if we consistently perform k simpler tasks z_i $(i = 1, \dots, k)$, with which performer (student, educator, teacher, etc.) is familiar, which are provided by the prior training and can be successful completed. Suppose that it is possible to set (measure) the execution time of each of the tasks z_i, and as a result of the execution it is possible to set: each of the tasks z_i is completed or not completed. If all the above conditions are fulfilled, then the problem z_i $(i = 1, \dots, k)$ will be called elementary problems for task Z.

The above definition of an elementary task is, by its nature, reminiscent of the definition of the classical probability of a random event through a complete group of elementary events. This similarity makes it possible to transfer many properties of classical probability in case of elementary problems. However, there are some differences in these concepts. In particular, all elementary events are equally likely, but for elementary tasks, as shown below, it is not always performed. In addition, the elementary events are insignificant in the order in which they are performed, but the elementary tasks must be performed in a certain order, otherwise the task Z may not be completed.

Each of the elementary tasks can be assigned its "weight" for the task Z. If we denote by $T(Z)$ the time required for its successful completion and by $T(z_i)$ the time required for the successful completion of the elementary task z_i $(i = 1, \dots, k)$, then "weight" of the elementary problem z_i for task Z we will call the number

$$\frac{T(z_i)}{T(Z)}.$$

Performing task Z, the condition of its timely execution must be fulfilled:

$$T(Z) = \sum_{i=1}^{k} T(z_i).$$

Each of the elementary tasks z_i for task Z can be characterized by another parameter, the value of which is set only after its execution – "success" of execution. Although it is assumed that an elementary task is familiar to the performer and he or she must successfully complete it, however, for a number of reasons, objective and subjective, the elementary task may be unfulfilled or incorrectly performed. It will affect the fulfillment of the task Z. Let us denote by $U(Z)$ the result of completing of the task Z, and by $U(z_i)$, respectively, the result of completing the elementary task z_i. The U function accepts only two values – 0 if the corresponding task is not completed, or 1 if it is successfully completed. Now it is necessary to set the numerical condition for completing the task Z. To do this, each of the elementary tasks z_i $(i = 1, \dots, k)$ must be fulfilled:

$$\prod_{i=1}^{k} U(z_i) = 1.$$

Thus, successful completion of task Z requires the fulfillment of both conditions: successful and timely completion of all its elementary tasks.

Considering that the fulfillment of task Z always begins with the fulfillment of the elementary task z_1, then the following can be a condition for the consistent execution of all elementary tasks:

$$U(z_1) = 1, U(z_i) \cdot U(z_{i+1}) = 1 \ (i = 1, \dots, k-1),$$

They should be checked after completing each of the elementary tasks. Unless individual elementary tasks require the required sequence of execution, they should be considered as separate tasks.

Therefore, the realization of fulfillment of all three of conditions: timeliness, success and sequence of completion of all elementary tasks for task Z are necessary and sufficient conditions for successful

completion of task Z. Now these conditions can be written in analytical form:

$$\begin{cases} T(Z) = \sum_{i=1}^{k} T(z_i); \\ \prod_{i=1}^{k} U(z_i) = 1; \\ U(z_1) = 1, U(z_i) \cdot U(z_{i+1}) = 1 \ (i = 1, \dots, k-1). \end{cases}$$

These conditions can form the basis of a mathematical model of the educational process. It should be noted that a task that is successfully completed can later be used as an elementary for a more complex task. It is clear that the time allotted for the task must have some tolerable (insignificant compared to the scheduled time) deviations, both upward and downward. These deviations should be taken into account at constructing the mathematical model of a particular education process.

3 Activity modeling and evaluation

In the previous paragraph, the numerical criteria for the successful completion of a specific training task were formulated. It is successful implementation depends on the performer's activity. This is a characteristic that is quite difficult to model. However, the elementary tasks method makes it possible to estimate it by setting the corresponding numerical value. To do this, we introduce the following notations.

Suppose that in order to successfully completed task Z, you must execute N elementary tasks. Denote by $N^{(+)}$ the number of elementary tasks that have been successfully completed and by $N^{(-)}$ – the number of elementary tasks that have not been completed. The equality must be executed:

$$N = N^{(+)} + N^{(-)},$$

that is, every elementary task is either completed or not completed.

Activity $A(Z)$ of the performer during the execution of the main task Z, we will define as the ratio of the number of completed elementary tasks to the number of all elementary tasks:

$$A(Z) = \frac{N^{(+)}}{N}.$$

This definition of the activity of the performer is, in fact, analogous to the definition of the classical probability of a random event equal to the ratio of the number of elementary random events contributing to the occurrence of this random event to the total number of elementary random events. It makes up a complete group of elementary events. Indeed, activity, like classical probability, satisfies the inequalities:

$$0 \le A(Z) \le 1.$$

In addition, if none of the elementary tasks is fulfilled, then the equality is satisfied: $A(Z) = 0$, but if the task is completed successfully, then the equality is satisfied:

$$A(Z) = 1.$$

It should be noted that the success execution of the elementary tasks and the sequence of their completion should not affect the performer's activity. Violation of this sequence must be taken into account after completing the entire task Z, in the analysis and evaluation of the work of the performer. This requirement can be formulated as a continuity of the education process.

So far, we have only considered one task performer. However, more than one performer can participate in the education process, and they can perform both joint tasks and individual tasks. The model of performing a single task by one performer was discussed above. Suppose now that task Z, with elementary tasks z_i $(i = 1, \dots, N)$, is performed by m executors. Denote by $N^{(+)}$ the number of successfully completed elementary tasks, and by $N_j^{(+)}$ $(j = 1, \dots, m)$ denote the number of elementary tasks successfully completed by the j-th performer. In this case, the following conditions must be observed:
1) Each elementary task is performed by only one performer, and only once, the equality must be fulfilled:

$$N^{(+)} = \sum_{j=1}^{m} N_j^{(+)}.$$

2) It should not be more executors than elementary tasks z_i $(i = 1, \dots, N)$ for task Z, that is, the inequality: $m \le N$ must be satisfied.

The described method of elementary tasks gives an opportunity to evaluate the work of the performer on the fulfillment of task Z. In our opinion, the performer can get a positive assessment even if this task is not successfully completed. The determinant should be the activity of the performer, as performance evaluation should encourage the performer and show progress in education. By the appropriate positive factor γ (multiplier of evaluation) can be set the mark $O_v(Z)$ of the work of the executor of task Z, by pre-scaling this factor according to the established rating system. For example, if all elementary tasks have approximately the same weight, then you can use the following value of the evaluation of task Z:

$$O_v(Z) = \gamma A(Z).$$

Otherwise, elementary tasks differ significantly in weight, then depending on the weight of each elementary task and the result of its execution, it is possible to establish another equality for evaluating of the execution of elementary task z_i For example, for the case of a 100-point evaluating system, we can put: $\gamma = 100$. Then, to evaluate the successful and timely completion of the elementary task z_i for the task Z can be taken the number:

$$O_v(z_i) = \gamma \frac{T(z_i)}{T(Z)} U(z_i) = 100 \frac{T(z_i)}{T(Z)} U(z_i).$$

The total score for task Z will be formed as the sum of the marks of each elementary task z_i for task Z:

$$O_v(Z) = \frac{\gamma}{T(Z)} \sum_{i=1}^{k} T(z_i)U(z_i)$$

$$= \frac{100}{T(Z)} \sum_{i=1}^{k} T(z_i)U(z_i).$$

From this equality it follows that with the successful and timely completion of all elementary tasks, the performer will receive a score of 100 points. If, however, one of the elementary tasks is not executed, then it does not bring a positive assessment to the overall assessment. Thus, the performance evaluation of the performer is directly related to his/her activity during task Z execution.

It is clear the actual execution time of a single elementary task, or the entire task, will be different from the planned values. In this case, it is possible to adjust the estimate by a value proportional to the tolerance of the corresponding parameter – to increase it if the actual execution time is less than planned, or to decrease otherwise. At the same time, it is necessary to ensure that the actual time of execution of the elementary task and the whole task does not exceed the set allowable values of deviation from the planned values of the corresponding parameter.

Let's consider this case. We introduce additional notations. Denote by $t(z_i)$ and $t(Z)$, respectively, the actual execution time of the elementary task z_i and the entire task Z. In addition, denote by $\Delta T(z_i)$ and $\Delta T(Z)$ absolute value of the tolerable deviation of the actual value from the planned for corresponding parameter.

The considered values must satisfy the following conditions:

– actual time of execution of task Z should not differ from the planned more than the planned deviation of this parameter:

$$|T(Z) - t(Z)| \le \Delta T(Z);$$

– the actual execution time of the elementary task z_i should not differ from the planned more than the planned deviation of this parameter:

$$|T(z_i) - t(z_i)| \le \Delta T(z_i);$$

– increased time for the execution of some elementary task reduces the time for the execution of other elementary tasks:

$$T(Z) + \Delta T(Z) \ge \sum_{i=1}^{k} \big(T(z_i) + \Delta T(z_i)\big);$$

– reduced time for the execution of some elementary task increases the time for the execution of other elementary tasks:

$$T(Z) - \Delta T(Z) \le \sum_{i=1}^{k} \big(T(z_i) - \Delta T(z_i)\big).$$

At execution of the above limitations, the planned evaluation for execution of0 the elementary task z_i can be changed by:

$$\gamma \frac{T(z_i) - t(z_i)}{T(Z)}.$$

The final evaluation for completing the elementary task z_i, in this case, will be calculated by the formula:

$$O_v(z_i) = \gamma \left(\frac{T(z_i)}{T(Z)} + \frac{T(z_i) - t(z_i)}{T(Z)} \right) U(z_i)$$

$$= \gamma \frac{2T(z_i) - t(z_i)}{T(Z)} U(z_i).$$

Thus, if the time for the elementary task z_i execution is increased, compared to the planned one, the estimate for its execution will decrease proportionally to the deviation, and in the case of decreasing it will increase. The formula for correction of evaluation performance of all task Z is similar:

$$O_v(Z) = \frac{\gamma}{T(Z)} \sum_{i=1}^{k} \big(2T(z_i) - t(z_i)\big) U(z_i).$$

If the result of calculations is a fractional number, then it is rounded according to the usual rules for rounding real numbers.

Using a valuation correction, you must keep in tolerable deviation to change for corresponding parameter. For example, for the 100-point grading scale used in higher education institutions, there are separate numeric intervals to translate it into the national rating scale. These intervals can be taken as a basis at using the correction of estimate. The middle of each interval can be selected as the base grade corresponding to that interval in the national rating scale. Then the correction of estimate will be within the appropriate interval of the 100-point scale.

Therefore, it is necessary to control the progress of each elementary task in order to exercise operational control over the educational process. To control it, we have identified two numerical parameters. One of them is the result of execution of a simple task. This parameter has discrete nature and may take one of two different numeric values, for example, 0 and 1 ("done", or "not done"). Another parameter is the time of an elementary task execution. This parameter is analog (continuous), and can take any numerical value (within the education process). If the education process is continuous, then the fixation of the time of execution of an elementary task can be reduced to the fixation of a moment that separates the execution of two consecutive elementary tasks. Below we will show how to identify (recognize) these two types of parameters and their values using an artificial neural network.

4 Interaction of educational process participants

The above scheme of organization of educational process can be implemented both without the use of hardware and software, and with their application. This

scheme has the greatest effect when used in cases of considerable intensity of the educational process, its saturation with a large number of various tasks, and engaging in the execution of the educational task of several performers. This situation occurs, for example, at of laboratory work executing by a group of higher education students. In this case, the student must successfully complete several operations in a certain sequence in order to achieve a positive result. The teacher should monitor the performance of several students at once, analyze the results and evaluate the execution.

For example, executing laboratory work "Lighthouse". Its aim is to study the work, capabilities and properties of the LED, the student and the teacher must jointly perform the following actions.

a) basic knowledge actualization;

b) explanation of the theoretical material by the teacher (the principle of operation of the LED and its design, auxiliary materials and equipment), in parallel with the demonstration of the necessary actions for the task;

c) familiarization of the student with the plan of laboratory work execution (issuing the task of laboratory work);

d) executing of laboratory work by the student under the guidance of the teacher;

e) executing laboratory work by a student independently;

f) task testing and bug correction, together with the teacher;

g) assessment of the student's work by the teacher, and deciding on the need for additional explanation and repeated performance of the student's laboratory task.

During the execution of the work, students must learn both theoretical material and acquire practical skills (table 1).

Table 1. Acquired skills as a result of work.

	Theoretical	Practical
Science (Physics)	• Knowledge in the Electricity Section • Knowledge of the physical parameters of devices	• Ability to create an electrical circuit • Ability to work with electronic devices • Ability to determine device parameters
Technologies (robotics, programming)	• Knowledge of signal coding technologies • Knowledge in the "linear programs", "cycles"	• Skills to create linear programs • Skills to create programs with cycles
Engineering (design)	• Knowledge in the section "Mechanics"	• Creating an existing structure • Modeling the appearance of the product
Mathematics	• Model of electrical circuit	• Be able to calculate parameters

The scheme of interaction of all participants of laboratory work is presented in Fig. 1.

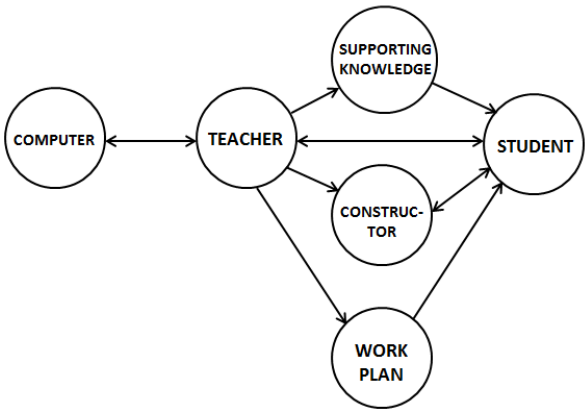

Fig. 1. The logic communication scheme at the laboratory work "Lighthouse" execution.

5 Conclusions

The proposed version of the method of elementary problems is quite universal. It can be applied both to individual topics of the curriculum, and to individual theoretical courses, workshops, etc. This will allow you to build a calculation of individual performance indicators in the vocational training system. Constructing of an artificial neural network to support a particular education process, certain criteria must be followed that can be controlled by the elementary task method described above. These criteria will, of course, depend on the nature, form and content of the process. They will be influenced by the goal to achieve through the education process. Before "constructing" the appropriate neural network, the teacher must clearly represent the whole education process and the desired results. For example, for the "Lighthouse (Led Blink)" laboratory work described above, the criteria can be the following:

– the student should try to complete all the tasks assigned to him in due time;

– the teacher should make full use of the planned time to activate basic knowledge and to familiarize students with the necessary theoretical and technical knowledge to perform the work;

– during the stages of explanation, self-completion of elementary tasks by the student, the teacher should explain these tasks, achieve their self-fulfillment by the student.

These criteria are easily written as numerical equalities. Its execution can be controlled by an artificial neural network. They can be considered by desirable values of the outputs of the neural network, to which it must approximate the corresponding actual values of these parameters. As a rule, minimizing the deviation of the desired output values of the neural network from the actual ones is carried out by the method of least squares, minimizing the totality of the target functions drawn up for this education process.

Summarizing the above, we can conclude that the use of elements of the theory of artificial neural networks in

combination with the method of elementary tasks makes it possible to significantly increase the efficiency of the educational process by strengthening its individualization.

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Semantic knowledge networks in education

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Abstract. The article is devoted to the modeling a semantic knowledge networks. The knowledge network is the basic concept of the problem of knowledge management. This is a new discipline that implements the principles of sustainable development of education. The method of constructing a semantic knowledge network allows us to analyze the connections between educational disciplines: "Economic Cybernetics", "Algorithms and Programming" and "Calculus". The paper compares the topological characteristics of the concept graphs related to various disciplines. We develop the algorithm to implement the subject area model in the form of a semantic knowledge network. 125 concepts are analyzed that provide optimal mastering disciplines and establish the connection between them.

1 Introduction

Problems of modernization of education in the framework of sustainable development are studied in many works [1-6].

The epidemics, the destruction of the natural environment and climate change, the depletion of material and energy resources, the population explosion and lack of food, as well as the civilization crisis as a whole, are complex interdisciplinary problems of the mankind. The need to resolve them leads to the emergence of areas of science that are characterized by convergence of methods and interdisciplinary approaches. Suprasectoral technologies (information, cognitive, nano-, bio-, social technologies) are currently being actively developed, which contribute to the emergence of new branches of science and serve as a new methodological basis for the nature study [7-9]. Such interdisciplinary scientific fields lead to new directions in science such as risk management, sustainable development, new nature management, etc. Quality of professional training students in the modern sense is determined by their willingness and ability to use the acquired professional competencies to solve not only professional tasks, but also multidisciplinary problems that may contribute to sustainable development at the level of the country, region and the world as a whole. This implies updating the content and methods of professional training of specialists at a modern university taking into account the requirements of interdisciplinary integration and the implementation of sustainable development ideas [10-14]. Interdisciplinary integration in higher education institutions has to be an important component of introducing sustainable development ideas into the training of modern specialists. The problems of sustainable development itself are multidisciplinary.

Such integration will solve the significant contradictions of education, namely the contradiction between the vast knowledge and limited human possibilities. The optimal combination of computer science and other academic disciplines within the same topic will provide conditions for a significant increase of the level of the educational process.

In [15] concluded that students have a large non-used potential to understand more deeply the nature of science and acquire the knowledge important for their future lives and work.

Recently, a lot of talk has been going on about the transition to a knowledge-based society. Knowledge management systems are being developed, and the knowledge management specialists are working in large corporations. Unfortunately, in the discussions of this topic higher education is not considered [16, 17]. It is unacceptable because the knowledge is created, systematized and accumulated within the universities and then it is passed on to the next generation of people.

The learning process is the management of the process of student's knowledge accumulation and systematization. Only a few researchers focus their attention on this fact [18–20]. An automated learning environment, built on the basis of semantic knowledge networks, is capable to a large extent of solving the wide range of knowledge management tasks in a university. A feature of the modern stage in the development of educational systems is the necessity of expending the use of formal methods for presenting knowledge and organizing the learning process. These trends are based on the use of the achievements of cybernetics, synergetic, and the theory of artificial intelligence. Many objects of cognitive science research should be described, as a network. Over the past two decades, many studies have

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focused on the network science methodology as an extensive scientific field of studying complex systems (for example, [21-24]). Complex systems contain several components that interact with each other, producing complex behaviour. Such a complex system is the human brain and the cognitive processes taking place in it. These processes provide memory and language (for example, [25–32]). Network science is based on mathematical graph theory and contains powerful quantitative methods for researching systems, such as networks (for example, [33]).

At this stage in the development of the education system, the priority is to find ways to improve the learning process, its content and structure. Receiving a fundamental and holistic education can be only as result of the learning process at the level of new quality. In this case the content of various disciplines should reflect the logic and structure of knowledge ties between disciplines. In the absence of intersubjective communications, the knowledge will be fragmentary, unsystematic. Cognitive networks are not only a tool for cognition, but can also a basis for controlling student's knowledge.

2 Analysis of previous studies

In different historical periods, many variants of semantic knowledge networks that take into account the specifics of intellectual activity have been created. In the "pre-computer era" the prototype of semantic knowledge networks was used to formalize logical reasoning. At the beginning of the twentieth century, in psychology, graphs were first used to represent hierarchies of concepts and inherit properties, model human memory and intellectual activity. In the early 1960-s the first machine implementations of semantic networks were made. In one of the first practically significant systems [34], 100 primitive types of concepts were introduced to solve the automatic translation problem. Dictionary of 15 000 concepts was defined.

At present, semantic knowledge networks are widely used in solving many different problems, in particular when building knowledge bases, in problems of machine translation and processing of text in a natural language. Due to the wide range of use of such graphs, there is a need for their refinement – an increase in the number of nodes and an increase in the connectivity between them.

Actual modern studies are devoted to the use of semantic networks in the field of education. For example, in the work [35] the interdisciplinary of applied mathematics is quantitatively analyzed by using statistical and network methods on the corpus PNAS 1999–2013. In article [36] discusses the potential Semantic Web for teacher education.

The paper [37] presents a theoretical method for the integration of semantic knowledge network utilization into the classroom. This paper will also introduce insights from Cognitive Linguistics as to how the brain best learns vocabulary. The method in this paper springs from the fields of psychology and neuroscience as well as inspiration from educators who are building new teaching styles. The purpose of the method detailed in this paper is to inspire other educators to incorporate cognitive linguistic insights into their classes as well as further the discourse on integrating this field into the teaching of English as a second or foreign language.

Authors [38] formulate recipe recommendations using ingredient networks. Researchers have shown how information about cooking can be used to glean insights about regional preference sand modifiability of individual ingredients, and also how it can be used to construct two kinds of networks, one of ingredient complements, the other of ingredient substitutes. These networks encode which ingredients go well together, and which can be substituted to obtain superior results, and permit one to predict, given a pair of related recipes, which one will be more highly rated by users.

With the traditional method of constructing a semantic knowledge network, its formation is carried out manually, which requires significant labour costs. Such networks contain a small number of nodes; nevertheless, they have an important advantage – their nodes and connections are checked manually and are correct. An alternative approach is the automatic construction of a semantic network based on an external source generated by Internet users [39]. A striking example of such a source is the Wiktionary [40].

Thus, all of these works are devoted to the integration of semantic knowledge networks in teaching. The increasing information volumes of the educational material of the disciplines dictate the need to use cognitive modelling to solve complex problems of training and teaching.

2.1 Theoretical framework

There are various ways of representing knowledge, in particular, such visual methods for describing knowledge in the subject field: semantic networks, graphs of conceptual dependencies, scripts, frames, conceptual graphics and ontology. Let's determine the definitions that are important for this work: "semantic knowledge network", "semantic network", "network model", "cognitive map", "cognitive network", "cognitive scheme". The connection diagram of these concepts is shown on Figure 1.

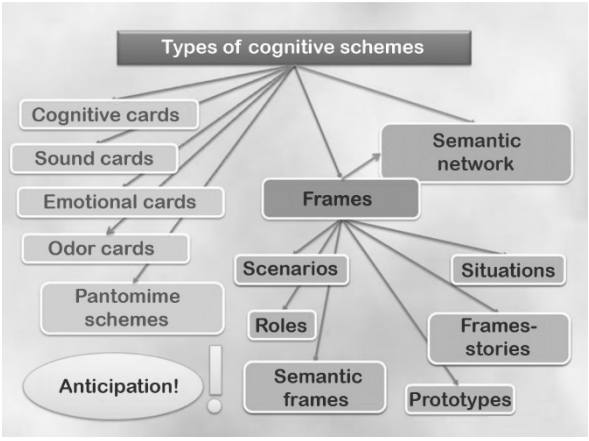

Fig. 1. Cognitive scheme type chart.

Cognitive maps are a concept from cognitive psychology and were first introduced by Tolman. A cognitive map is an active, information-seeking structure.

In our work, the concepts of "semantic knowledge network" and "semantic network" are equated based on their proximity.

In cognitive science the network is one of the most common types of information models. Typically, a network consists of two components – nodes as network elements and edges, reflecting the interaction between the elements. Using these simple components, you can describe a wide range of objects of different nature and complexity. The network models are based on the concept of network. In such models, all relations are explicitly highlighted. These relations constitute the framework of knowledge of the subject area, the model of which must be created. This class of models includes semantic networks, functional networks, and frames (frame representation).

Although the terminology and structure are different there are similarities inherent in almost all semantic networks:

- different nodes of one concept belong to different values, if not it is marked that they relate to one concept;
- edges of semantic networks create relationships between concept nodes (marks above arcs indicate the type of relationship);
- relations between concepts can be linguistic cases, such as "agent", "object", "recipient" and "instrument" (others mean temporal, spatial, logical relations);
- the concepts are organized by level in accordance with the degree of generalization.

An associative approach to knowledge representation defines an object value in terms of its connections (associations) with other objects. Thus, when a person perceives an object and discusses about it, in this time a perceived object is mapped into a certain concept (Fig. 2). This concept is part of the general knowledge of the world, so it is connected by various associations with other concepts. Associations define properties and behaviour of the perceived object.

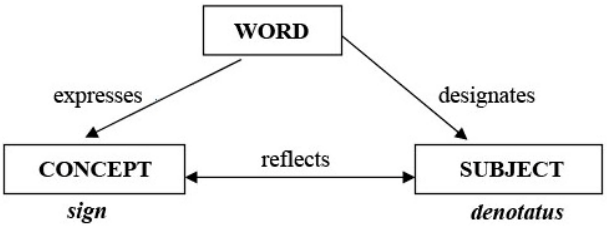

Fig. 2. The relationship of the concept, subject and word denoting this subject [41].

Graphs are best suited for explicitly expressing associations between different concepts. Thus, in the form of a semantic network, knowledge of the world is expressed. A semantic knowledge network is a marked graph in which nodes correspond to certain facts or general concepts, and edges mean relationships or associations between different facts or concepts (Fig. 3).

In each academic discipline (in every science) the number of concepts reflecting the knowledge of this discipline (this science) is finite. There are a number of words that need to be conveyed to the audience. The number of these words is not infinite, because time for their transfer is limited. Textbooks establish linear links between concepts.

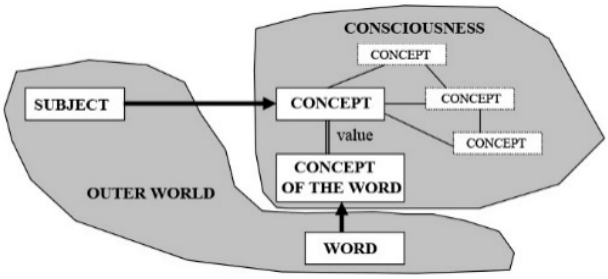

Fig. 3. The relationship of various concepts in the human mind [41].

A normalized description of knowledge networks can be formulated as follows. The body of knowledge of the studied discipline is a system (*S*). The elementary component that is part of *S* is a word that reflects a certain concept. With the help of words, all the concepts that make up the *S* system are recorded. Links between the concepts are established using the grammatical rules of a particular language. With respect to each concept from *S*, there is a primary sentence that contains its definition. The totality of such definitions forms an invariant kernel *S*, which ensures the unambiguity of the perception of knowledge within a particular academic discipline. The invariant core of the discipline uses words from other areas of knowledge to determine its concepts. All concepts from *S* are divided into main and auxiliary. The basic concepts include specific concepts of this particular discipline, which are the subject of its definition and study. Supporting concepts include concepts borrowed from other areas of knowledge that are not studied in this discipline, but are used to determine the content of basic concepts. Many of the basic concepts of a particular discipline, together with the internal relationships between them, form a hierarchically ordered network of knowledge, the nodes of which are the identifiers of the basic concepts.

Thus, the knowledge system can be represented in the form of a hierarchical directed graph – a semantic knowledge network.

The semantic knowledge network building algorithm involves several steps:

(1) Writing all the basic terms of the subject area and formulate their definitions (composing the thesaurus of the subject area).

(2) Selecting the terms from the list that appear in the definition of the other terms listed in step 1.

(3) At the lower (I) level, arranging the terms in the definition of which the terms from the list are not used.

(4) At the next (II) level, arranging the terms in the definition of which the terms of level I are used.

(5) At the III level – terms in the definition of which the terms of I and II levels are used, etc.

(6) At the last level, arranging terms that are not used in the definition of other terms.

(7) Connecting the concepts.

Visualization of data in a structural network model is the first step, but the strength of the method lies in the ability to extract important knowledge about the system through a statistical analysis of the network topology. It seems that topology bears an evolutionary imprint and functional [42]. A detailed analysis of the available metrics can be found, for example, in [43]. Consider just a few metrics often used in cognitive model research.

Let us consider in detail the network structure. A network consists of nodes and links between them, edges. Nodes are more or less stable entities that do not change over time.

Edges represent relationships, interactions, transactions, or any other temporary connections that occur between nodes over a certain period of the time. Edges represent connections between them: friendships, proximity, transactions, exchanges and any other temporary connections between stable objects that occur with a certain frequency.

Edges are important to network analysis because they represent the connectivity basis that will be using to get insights about the complexity network. In a graph database, the relationships between the data are just as important as the data itself.

Giant component is an important notion in network analysis. It's an interconnected constellation that includes most of the nodes in a network.

Clusters are the constellations of nodes that are more densely connected together than with the rest of the nodes in the network. Clusters represent different sub networks within a network and can be used to identify various subcategories that are present within.

In modern network theory, the number of node connections (in the theory of graphs, nodes and nodes are edges and vertices of a graph, respectively) is called a degree. A node's degree indicates how many connections it has to the other nodes in the network. The more degree a node has, the more "connected" it is, which indicates its relative influence in the network.

The concept of degree is a local characteristic of a graph. A nonlocal, integral network structure is defined by two concepts – a path and a loop or cycle. A path is a sequential sequence of adjacent nodes and the links between these nodes when the nodes do not repeat. A loop or cycle is a path when the start and end nodes coincide. Networks without loops are trees. The number of nodes (N) (network size) and the number of links (L) are related as $N = L - 1$ [23].

Identifying the nodes with the highest degree (also called "hubs") is an important part of network analysis as it helps identify the most crucial parts of the network. This knowledge can then later be used both to improve network's connectivity (by linking the hubs together) and disrupt it (by removing the nodes).

Betweenness centrality is another important measure of the node's influence within the whole network. While degree simply shows the number of connections the node has, betweenness centrality shows how often the node appears on the shortest path between any two randomly chosen nodes in a network. Thus, betweenness centrality is a much better measure of influence because it takes the whole network into account, not only the local connectivity that the node belongs to.

A node may have high degree but low betweenness centrality. This indicates that it's well-connected within the cluster that it belongs to, but not so well connected to the rest of the nodes that belong to the other clusters within the network. Such nodes may have high local influence, but not globally over the whole network.

Alternatively, other nodes may have low degree but high betweenness centrality. Such nodes may have fewer connections, but the connections they do have are linking different groups and clusters together, making such nodes influential across the whole network.

In network visualization we often range the node sizes by their degree or betweenness centrality to indicate the most influential nodes.

Network topology is an important element of network analysis. If we analyses networks on the structural basis we will discover many differences among them. A tool for studying complex networks based on graph theory is topological analysis.

When performing network analysis and visualization it is important to classify the topology of the network [44]. This can be done through quantitative analysis of degree distribution among the nodes and/or through qualitative analysis using various visual graph layouts.

Degree distribution can be a good indicator of the network's topology. If most of the nodes in the network have exactly the same degree, the network is more of a regular one (it may also indicate the presence of tree-like hierarchical system within the network). If most of the nodes have an average number of connections that is the same and then some of the nodes have more and some of the nodes have less (normal bell-curve distribution of degree), we're dealing with a randomized network. Finally, if there's a small, but significant number of nodes with a high degree and then degree distribution follows a long tail towards a gradual decline (scale-free distribution), this is a small-world network, where there's a significant amount of well-connected hubs, which are surrounded by less connected satellites, which form clusters. Those clusters are connected to one another via the hubs and the nodes that belong to several communities at once.

Graph layout a qualitative measure for identifying topology of a network. A very useful type of layout is Force Atlas, where the most connected nodes with the highest degree are pushed apart from each other, while the nodes that are connected to them but have lower degree are grouped around those hubs. After several iterations this sort of layout produces a very readable representation of a network, which can be used to better understand its structural properties and identify the most influential groups, differences between them, and structural gaps within networks.

Network motifs are the different types of constellations that emerge within network graphs. They can provide a lot of useful information about the structural nature of networks.

For example, some networks may be comprised of dyads or pairs of nodes (which indicates that the level of overall connectivity is quite low). Some other networks can have a high proportion of triads, which usually

indicate the presence of feedback loops, which makes the resulting network formations much more stable. More complex formations include groups of four nodes that can be connected as a sequence or between each other, forming interconnected clusters that can encode certain levels of complexity that go beyond simple triad feedback constellations.

It is important to take notice of the network motifs that emerge within a network because it will provide a very good indication of the level of complexity and thus the capacity of the network.

Modularity is a quantitative measure that indicates the presence of distinct communities within a network. If the network's modularity is high, it means it has a pronounced community structure, which, in turn, means that there's a space for plurality and diversity inside. If the modularity is too high, however, it might also indicate that the network consists of many disconnected communities, which are not globally connected, making it much less efficient than an interconnected one.

Modularity works through an iterative algorithm, which identifies the nodes that are more densely connected to each other than to the rest of the nodes in the network. It will then calculate the measure of modularity for the network at large. The higher this measure is, the more distinct those communities of densely connected nodes are. If the modularity measure is 0.4 or above it means that the community structure in the network is quite pronounced. If it's less it means that there are no big differences between the different clusters and most of the nodes are equally densely connected to each other across the whole network.

So far, we've looked at the different measures of connectivity that exist within networks and that help us identify the most influential nodes, clusters, and deduce some basic functional properties of the networks we study.

However, one of the most important aspects of network graphs is that they also let you see the gaps, empty blank spaces, between the islands. Those gaps are usually referred to as "structural gaps" and it has been shown that bridging those gaps can spur innovation, create most interesting collaborations, and give rise to new, unexpected ideas.

In other words, "structural gaps" is where creativity and potential are hidden within the network. Therefore, when visualizing a network, it is important to identify those structural gaps and to devise different actions that could help bridge different nodes and clusters across those empty spaces within the graph in order to spur creativity and innovation.

3 Results and analysis

As an example of modeling semantic knowledge networks, we analyze the relationship between the concepts of academic disciplines. As you know, that discipline mastering is closely connected with the assimilation and comprehension of the course concept thesaurus. To assimilate further concepts within the framework of this discipline, it is necessary to understand the already learned, often in the framework of the already studied disciplines. Therefore, an actual task is to study the dependencies between concepts and to model them, using cognitive networks [44].

The Fig. 4 shows a fragment of the construction of a semantic knowledge network.

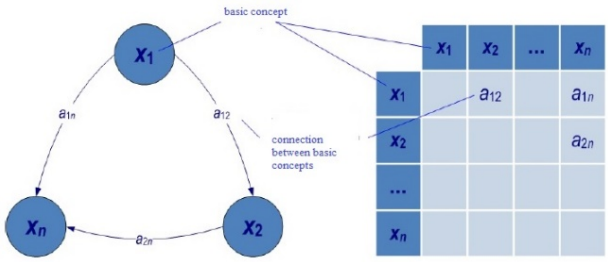

Fig. 4. The semantic knowledge network diagram.

To implement the subject area model in the form of a semantic knowledge network, we propose the following algorithm:

(1) Classification of all concepts of the subject area into macro concepts (class of concepts), meta-concepts (generalized concepts) and micro-concepts (elementary concepts).

(2) The allocation of common properties, characteristics inherent in each level of concepts.

(3) Highlighting the hallmarks of each level of concepts.

(4) Establishing links between concepts related to the same level.

(5) The allocation of inter-level ties.

We have analysed 125 concepts that are necessary for the "Economic Cybernetics" discipline mastering and the relationship between them (communication means the need for one concept to master another). We conducted a similar study for 125 concepts of the "Algorithms and Programming" and 125 concepts of the "Calculus" discipline.

The constructed graphs (Fig. 5–7) can be used to identify the most important concepts that have the highest degree of apex, as well as concepts that are in the way of studying other important course concepts. The obtained graphs were visualized using the Gephi software product [45].

Gephi is free open-source, leading visualization and exploration software for all kinds of networks and runs on Windows, Mac OS X, and Linux. It is highly interactive and user can easily edit the node/edge shapes and colors to reveal hidden patterns. The aim of the Gephi is to assist user in pattern discovery and hypothesis making through efficient dynamic filtering and iterative visualization routines.

Gephi allows to calculate the topological characteristics of the graph, as:
- nodes and edges (what networks are made of);
- clusters (groups of nodes that are connected);
- degree (the number of connections that the node has);
- centrality between (how influential a node is);
- modularity (community structure).

Gephi comes with a very fast rendering engine and

sophisticated data structures for object handling, thus making it one of the most suitable tools for large-scale network visualization. It offers very highly appealing visualizations and, in a typical computer, it can easily render networks up to 300 000 nodes and 1 000 000 edges. Compared to other tools, it comes with a very efficient multithreading scheme, and thus users can perform multiple analyses simultaneously without suffering from panel "freezing" issues.

Fig. 5. The semantic knowledge network of the course concepts "Economic Cybernetics".

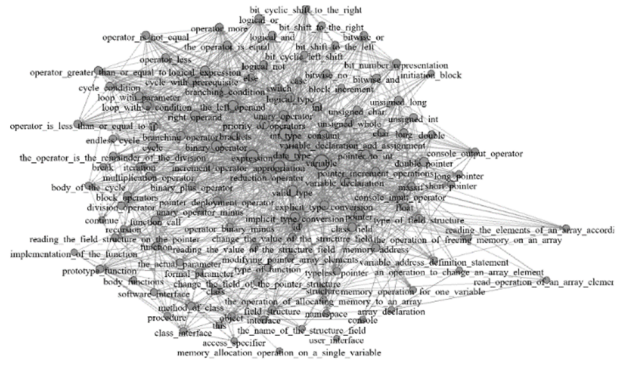

Fig. 6. The semantic knowledge network of the course concepts "Algorithms and Programming".

Fig. 7. The semantic knowledge network of the course concepts "Calculus".

In large-scale network analysis, fast layout is a bottleneck as most sophisticated layout algorithms become CPU and memory greedy by requiring long running time to be completed. While Gephi comes with a great variety of layout algorithms, OpenOrd [46] and Yifan-Hu [47] force-directed algorithms are mostly recommended for large-scale network visualization. OpenOrd, for example, can scale up to over a million nodes in less than half an hour while Yifan-Hu is an ideal option to apply after the OpenOrd layout. Notably, Yifan-Hu layout can give aesthetically comparable views to the ones produced by the widely used but conservative and time-consuming Fruchterman and Reingold [48]. Other algorithms offered by Gephi are the circular, contraction, dual circle, random, MDS, Geo, Isometric, GraphViz, and Force atlas layouts. While most of them can run in an affordable running time, the combination of OpenOrd and Yifan-Hu seems to give the most appealing visualizations. Descent visualization is also offered by OpenOrd layout algorithm if a user stops the process when ~50–60% of the progress has been completed. Of course, efficient parameterization of any chosen layout algorithm will affect both the running time and the visual result.

In Fig. 5–7 the size of the nodes-concepts of semantic knowledge networks characterizes the degree of importance and fundamentality of the corresponding terms of the academic discipline.

For the obtained graphs, their topological characteristics were calculated and analyzed. The results of the study are shown in Table 1.

Table 1. Comparison topological characteristics of the graphs of the relationship between the concepts of the disciplines: "Economic Cybernetics" (E), "Algorithms and Programming" (P) and "Calculus" (M).

Parameters	E	P	M
Nodes	125	125	125
Weakly Connected	3	1	7
Strongly Connected	111	121	113
Diameter	5	9	3
Average Shortest Path-length	2.21	3.416	1.806
Network Density	0.17	0.11	0.20
Average Degree	21.45	13.66	24.18
Modularity	0.25	0.30	0.23
Clustering Co-efficient	0.40	0.33	0.59
No. of Clusters	1	1	1

Let us analyze the found values of measures (Table 1). The Link Density measure is a measure of the density of edges, calculated as the ratio of the number of edges of a graph to the corresponding number of vertices and determines the maximum number of edges in a given graph. Thus, the values 0.17 – for the graph of discipline "Economic cybernetics" and 0.2 – for the "Calculus" means that the edges are filled with about 17.3% and 19.5% of the maximum possible respectively. The density of the graph of concepts of the discipline "Algorithms and Programming" is less: 11%, which can be explained by a smaller number of connections between concepts on average in the graph.

The maximum degree of 121 vertices was demonstrated by the concept graph in the "Algorithms and Programming". The maximum value of the degree of the vertex in the column "Economic cybernetics" – 111. The minimum degree of vertices in the graphs "Economic Cybernetics" and "Algorithms and Programming" are 3 and 1, respectively, which are almost the same. For

"Calculus", the number of weakly connected nodes is higher – 7, and strongly connected – 113, which is less than in "Algorithms and Programming", but more than in "Cybernetics".

It also confirms a greater connection between the concepts of the "Economic cybernetics" and "Algorithms and Programming" than the concepts of the "Calculus".

Mean average node degree for the "Economic Cybernetics" graph is 21.45, and for the "Algorithms and Programming" graph – it is 13.66 and for the "Calculus" – 24.18. This is confirming the presence of more connections in the last graph.

The global clustering coefficient (clustering) for a graph is the ratio of the number of vertically connected triples of vertices to the number of triangles (cyclically connected triples of vertices). For the "Economic Cybernetics" graph, the clustering coefficient is 0.4, for the "Algorithms and Programming" graph – it is 0.33, and for the "Calculus" – 0.59. This means that the concepts of the "Calculus" course are more often on the path to mastering other important concepts.

As for the diameters of the graphs – for the "Economic Cybernetics" concept graph the diameter value is 5, for the "Algorithms and Programming" graph – 9 and for "Calculus" – 3. The same relationships are observed for average shortest path-lengths. Which may mean the existence of longer paths in the connections between the "Algorithms and Programming" discipline concepts.

The modularity index is less than 0.4, which means that the structure of communities in all three networks is not sufficiently expressed.

In the field of education, there is always a problem of the contradiction between increasing the amount of scientific information and limiting the time allotted for its assimilation. Teaching academic disciplines in higher education requires constant work on educational information in order to move from extensive to intensive teaching methods. Teaching academic disciplines in higher education requires constant work on educational information in order to move from extensive to intensive teaching methods. One of the ways to intensify the educational process can be the optimal "packaging" of educational information.

The solution to this problem is the construction of a semantic network. An important condition for the successful mastering of educational material is the ability of the teacher to highlight the key issues of the program. Nodal issues of the program are the basis for studying the whole topic. Their significance can be determined using a graph or adjacency matrix.

For example, let a topic contain 6 questions and the logical connections between them are presented in the form of an adjacency matrix (Table 2).

Table 2. Example topic adjacency matrix.

	P_1	P_2	P_3	P_4	P_5	P_6	α_B
P_1	0	1	1	0	0	1	3/6
P_2	0	0	1	1	1	1	4/6
P_3	0	0	0	1	1	0	2/6
P_4	0	0	0	0	1	0	1/6
P_5	0	0	0	0	0	0	0
P_6	0	0	0	1	0	0	1/6

The significance of the question can be characterized by the weight coefficient determined by the formula: $\alpha_B = S_i/k$ where S_i is the number of references to the i-th question when studying the others contained in this topic, k – is the total number of questions in this section. The larger the coefficient leads to the greater the significance of the issue. Thus, it is possible to determine the importance of the discipline (section) in the study of all disciplines of the curriculum. A similar technique can be used in the formation of the content of academic subjects on the basis of discipline standards, in the development of curricula and tests, in the selection and organization of educational information for training.

4 Conclusions

Algorithms for the formation of a semantic knowledge network are developed. The knowledge network is the basic concept of knowledge management. In fact, we introduce a new discipline that implements the principles of sustainable development of education. The method of constructing a semantic knowledge network of terms allows forming an adjacency matrix that reflects the correlation of terms from a terminological dictionary. This matrix allows to evaluate the quality of the terminology in the particular discipline, as well as to determine quantify the semantic connectivity of the whole tutorial. According to obtained results, we can conclude that the concept system in the "Economic Cybernetics" is connected and complex. This means that in this case when studying any concepts, it is necessary to repeat the meaning of those already studied. The concept system in the "Algorithms and Programming" contains fewer dependencies and less connectivity in comparison with graphs. But the experience of studying these disciplines indicates that also the "Algorithms and Programming" is not easy to learn. Further the problem of planning the learning process based on semantic networks of knowledge will be studied. Namely, the distribution of lectures, practical and laboratory exercises will be determined to achieve successfully the learning objectives. In future work, we will to calculate spectral characteristics of graphs for the studied disciplines, as it was done in [50, 51].

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Psycho-pedagogical training as a mean of forming the occupational stress resistance of future teachers

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Abstract. Peculiarities of psycho-pedagogical training, and its role in the preparation of the future teachers for the preservation and strengthening of occupational health, formation of their professional stress resistance, and harmonization of personality are revealed in the article. Activity of the training group was described, aimed at: formation of skills of productive interaction and constructive overcoming of professional difficulties, formation of strategies of protection against stress, teaching of methods and techniques of self-regulation, formation of sanogenic thinking. Dynamics of psychological indicators of the occupational health of future teachers, who took part in the work of psycho-pedagogical training, was checked. Quantitative and qualitative analysis of the results of diagnostics (research of responses, self-reports of participants of training about their state of health, change of way of life or thinking, ways of interaction with others) was carried out. The effectiveness of psychological and pedagogical training as a means of forming professional stress resistance of future teachers has been proved.

1 Introduction

Nowadays occupational stress is a serious threat to future teachers' health. The World Health Organization called occupational stress the disease of the 21st century because this stress is common in any profession and has become a global epidemic. Modern teachers, as the representatives of the stressful profession, need protection. To build the resilience of future teachers at the stage of their professional training has become an effective way to protect them from occupational stress is.

Resistance to stress matters in ensuring the effectiveness and reliability of pedagogical activity. Stress resistance is one characteristic of the individual that means the ability to overcome occupational stress. Stress resistance helps the teacher to protect their personality from disintegration; various disorders create the basis for internal harmony, high efficiency, and determines the state of teachers' occupational health.

The analysis of the sources shows that modern psychological science has a large arsenal of managing stress states techniques, ways of optimizing the functional states of a person, methods of preventing negative emotional states that can be used at the stage of the occupational training of future teachers. There were some attempts made to develop different courses for this reason in some Ukrainian and foreign institutions of higher education: "Psychophysiology of Professional Activity"; "Psychology of Health"; "Medical Pedagogy"; "Culture of Health"; "Culture of Occupational Health"; "A Healthy Lifestyle"; "Health Saving Pedagogy"; "Prevention of the Occupational Burnout Syndrome among Teachers". In most cases, the developed programs of information-prophylactic and physical-fitness orientation focus on formation of students' healthy lifestyle.

The literature review gives grounds to claim that the research is aimed at preventing stress from teachers. Insufficient attention is paid to shaping the resilience of future teachers. Despite the considerable amount of work on this problem, the ways of its formation by future teachers are still unexplored. Therefore, in the problem's context under study, the question of finding ways and means of forming the professional stress of future teachers is urgent. In the arsenal of such tools, there are different training. Among them, we note: training of development of stress resistance of specialists of socio-economic professions, developed by G. Dubchak [1]; training "Prevention of professional burnout syndrome among teachers" by T. Zaychikova [2]; training of formation of professional stress resistance of future teachers O. Markovets [3]; training programs for raising the level of professional stress of special educators, by N. Tsybulyak [4] and a group of E. Kiel, U. Heimlich, R. Markowetz, A. Braun and, S. Weib [5], etc. Noteworthy are anti-distress training, anti-burn training,

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and personal-professional training for teachers of the Academy of Innovative Development of Education (the project of the Ministry of Education and Science of Ukraine and the National Academy of Educational Sciences of Ukraine).

The purpose of the article is to reveal the role and test the effectiveness of psychological and pedagogical training as a means of forming the professional stress of future teachers.

2 Methodology

2.1 General background of research

In the scientific literature, the concepts of "emotional stability", "psychological stability", "stress resistance", "stress tolerance", "frustration tolerance", "resilience," are synonymous terms for stress resistance.

Emotional stability is a characteristic that describes an individual in the process of intensive activity. Scientists call the major components of emotional stability the adequacy of emotional assessment of situations, the conformity of emotional reactions, and the harmony of relationships between all components of activity in emotional conditions. The terms mental stability and psychological stability are treated as synonyms in the scientific literature. Mental resistance is a complex personality feature that combines balance and resilience (stability, persistence). At the heart of frustration tolerance as the ability to counteract life and professional difficulties without loss of psychological adaptation is the ability to assess the real situation and the ability to find the way out. Emotional stability in the scientific literature is interpreted as the ability of the individual to maintain resilience under the influence of external and internal threats without losing pace of development Resilience refers to a dynamic process that implies a positive adaptation in significant problems [6].

Professional stress resistance determines the ability to withstand stress effects, negative factors of the pedagogical activity, stressful situations, ability to find their resources in difficult conditions of professional activity [7]. The process of stress management is determined by the individual capacities (resources) used to realize it, and by behaviour strategies and methods of action in a stressful situation that can be constructive and non-constructive. These factors shape the mechanisms of mental regulation of stress management and characterize the essence of this process [8]. Forming future teachers' stress resilience involves foremost, eliminating potential sources of stress in their inner world.

In our study S. Gremling and B. Auerbach's stressors classification is important [9]: controllable stressors, non-controllable stressors, and identified stressors. While dealing with managed stress factors, training (communication training, behavioural training, and personal development training) is the most appropriate. Dealing with uncontrollable stress factors requires changing the assessment of factors as stressful with the help of rational-emotional means and self-regulation of emotional states. Stress management is managing stress, which comprises three main directions: prevention of stress factors, reduction stress from stressors and organization of the system of elimination of negative consequences [10]. Thus, training of mental self-regulation skills, the constructive overcoming of professional difficulties, methods of analysis, interpretation and realistic assessment of stressful situations, mastering constructive handling strategies, the development of the sanogenic thinking, etc. are essential to developing professional stress resistance.

2.2 Instruments and procedures

The psychological and pedagogical training, which we have produced, is a means of forming the professional stress resistance of future teachers. Training as practical psychological work is a means of organizing conditions for self-disclosure of participants of the training and autonomous search for the ways of solving their psychological complications. The training is an effective social and psychological education, where the purpose is the acquisition of cognitive knowledge and many practical skills.

Forty students of the second course of pedagogical specialties (future teachers of geography, biology, and chemistry) of the Ternopil Volodymyr Hnatiuk National Pedagogical University named took part in the training's activity groups.

Psycho-pedagogical training is based on the principles of active socio-psychological training. It is a holistic dynamic system of training exercises. Activities of the training group were aimed at creating an atmosphere of goodwill, trust, safety, and security that facilitates the identification of future teachers' psychological problems. During the training, through interpersonal interaction, there is the disclosure of the personal perspectives of the members of the group and its psycho-correction. We focused on the psychological and pedagogical training, not only one solution of personal psychological problems but also on the disclosure of internal potential of the personality, formation properties and qualities that determine the ability to withstand professional stress.

In creating the training program, we relied on principles, used technologies and exercises from other methods of active social and psychological training. The methodological basis for the development of the training program is the teaching of humanistic psychology on the self-perception and self-actualization of the individual, his adequate personal growth. The rational-emotional approach (A. Ellis) became the theoretical and methodological basis of activity for forming professional stress resistance [11], according to which the central link in occurrence of stress is the subjective assessment, and the theory of psychological stress (R. Lazarus, S. Folkman) [12], according to which the main link that causes the stress response is cognitive assessment, determined by the interaction of personal factors and environmental stimuli.

The program of psycho-pedagogical training covers 10 group sessions with a total volume of 40-50 hours.

The main tasks of psychological and pedagogical training are aimed at starting the process of development of adequate self-esteem, development of sanogenic thinking, constructive interaction and creation of activate psychological mechanisms of self-regulation. The activities of the training group are aimed at forming stress resistance as the ability to find their resources in difficult situations, developing the ability to recognize their emotional state; formation of positive self-concept and assertive behavior; prevention of undesirable qualities, deformities of personality; teaching the basics of self-regulation of stress states; development of readiness for self-change and self-development in professional activity.

The activity of the training group involves updating the personal and neuro-psychic resources of its members, in particular, active strategies of overcoming behaviour, awareness and reduction of the destructive influence of accentuations and temperament, resolving of intra-personal conflicts. Future teachers are learning to model behaviour in stressful situations, to understand their emotions, to reduce the height of the situation with the help of game tools, the use of different psychotherapists, to focus on the positive.

Future teachers' participation in the training's workgroup contributes to the knowledge of their strengths and weaknesses, the gradual elimination of the neurotic components of their inner world, the improvement of interaction with other people, the harmonization of the integral qualities of the individual. Training creates conditions for the development of such qualities as flexibility in communication, self-confidence, reflexivity, tolerance. Psycho-pedagogical training helps to master the psych techniques of subjective self-influence. We should also mention that the system of psychological influences is directed at the development of stress resistance of future teachers, it is not general in its nature, but is created based on the students' characteristics.

The operational aspect of the group process in the training group is structured according to the principles of active social and psychological training. One of the main (basic) methods of training is a group discussion since it is almost always included in all other methods in one or another modification. Also, the training group used such methods of work as role-playing situations, psychodrama, psychological games and exercises, psycho-images, psycho-gymnastics, meditative psychological techniques and exercises-relaxation, parable therapy. Methods of psychological and pedagogical training are presented in our article [13].

Psychological and pedagogical training, as active social and psychological training, is based on the processes of positive disintegration and secondary integration of personal structure. It means that the work of the training group is aimed at the disintegration (weakening) of illusory perceptions, which have been created because of the subjective integration by a member of the group of their behaviour – an integral part of the "psychological protection" system. The entire system of "psychological protection" is associated with the deformation of thinking about one's "I", which is supported by insufficient knowledge and unconscious "belief" in the flawlessness of one's "I". Such positive disintegration makes it possible to uncover the true causes of the disintegration of the subject's personal structure. Under the conditions of active social and psychological training, positive disintegration creates an environment for the emotional and personal rapprochement of a member of the group and the people around him, enhancing his capacity for empathy and understanding. Thus, it opens the way to the creation of a new multilevel integral personality structure at a higher level of psychological development [14].

An important psychological point for psycho-pedagogical training is to create confidence in the participants that the attitudes can be changed only through constructive changes of their own behavioral emotional-rational experience. Training shapes the settings of self-control, tendencies towards planning and changes in one's own communicative behaviour, lifestyle, and thinking.

In the training's workgroup, the following stages of development were observed: initial, working and final.

The initial stage lasted two sessions. At this stage, we informed the participants about the peculiarities of the training group, its goals, and diagnosed the personal problems of the training participants, revealed the motives for participation in the group, the expected results.

The determination of personal issues was facilitated by the discussion: "Understand yourself – and you'll understand the world and become stronger"; "The trust phone exercise" (the group members asked a trust telephone specialist such questions as "How to increase self-esteem?"; "How to control anger?"; "How to become life-sustaining?"; "How to get rid of excessive anxiety?"; "Can I learn how to manage my emotions?"; "How to learn not only to speak but also to think positively?"; "What to do with the influence of the insult?" etc.). Performing the exercises "Motto"; "Wheel of life"; "Symbol of health" helped participants of the group to enter the process "softly", become more relaxed. The participants of the group did their homework – to perform psycho pictures on the theme "I am real, I am perfect" "I and the group".

The second session was devoted to the empirical measurement of the characteristics of members of the group "I perceive you ..." the primary reflection of my image "Me" in the eyes of other students. When performing this task, one felt emotional tension, stiffness of the group members. Therefore, at the end of the classes, relaxation exercises "Star Screen"; "Strawberry Meadow" were performed.

At the initial stage, the focus was on the knowledge of the other person (the members of the group did the "Interview" exercise with great interest, the essence of which was to plan questions to each member of the group to better know the others, while when performing the "Strengths" exercise by the end of the initial stage, an atmosphere of emotional closeness was felt, trust was created, and disintegration concerning the emotional sphere of students.

The next, four-session work stage was marked by considerable emotional stress, cognitive disintegration, which was because of deep analysis by the group members of the causes of their problems in dealing with other people, internal discomfort, and anxiety. The tasks envisaged at this stage had to activate the positive potential of future teachers, to strive for constructive personal change, to have a great psychological load. These are: modelling of pedagogical situations and their solution (with elements of dramatization), role-playing game "I am a classroom leader: first acquaintance with a class"; performing exercises aimed at the development of sanogenic thinking ("Flushing"; "Dissolution of the image"); exercises that promote the formation of skills of assertive behaviour ("Decent response"; "Request – refusal"); discussions on the topics "Secrets of pedagogical interaction"; "How to resist stress and burnout in pedagogical activity"; "Constructive overcoming difficulties in pedagogical activity"); analysing and reproducing situations that students have cited from their own experiences.

Modeling and analysis of various situations created conditions for testing new forms of communicative behavior, understanding the causes of difficulties in interaction with other people, impaired mental equilibrium, deteriorated state of health. At this stage, students were expanding the "front" of self-discovery and self-understanding, and multilevel positive disintegration was taking place. This is evidenced by the depth of analysis of their behavior and behavior of others, awareness of the causes and difficulties, the quality of performance of psycho pictures, other homework (exercise "Letter to yourself"; "Inventory of defects").

In the third, final stage of development of the training group, positive disintegration is completed by secondary integration. Future teachers strive for self-change, self-creation. They realized that the process of self-exploration and self-improvement does not end with the completion of training, and participation in training is only a step to a constructive change in their behavior, thinking, and lifestyle.

Each lesson began, like the previous ones, by reading the parable, analysing it, and discussing it ("All external changes in a person begin with a change of thoughts"; "How to discover and develop your inner potential"; "Secrets of the teacher's mental equilibrium"; "Steps to the assertive behaviours"; "Constructive coping strategies"; "Professional careers without stress"; "How not to burn in the flames of the profession"; "Change the thinking–change yourself and your life"; etc.), during which members the groups expressed their thoughts, feelings, doubts. At the class, students exchanged impressions of their previous class, analyzed psychopictures, and performed open sociometry. The members of the group gave each other already full psychological characteristics (games "Thoughts on character"; "Prosecutor and lawyer"; exercise "Suitcase"; "What would you take from another person for yourself, what would you give her, what would you throw away?"). During the exercise "Me, perceived with the eyes of the other members of the group" (lesson 9), each participant expressed his or her ideas about how the group perceives him/her. The group acted as a collective expert, correcting one whose views diverge from the true perception of his group. Participants even made predictions about what could be an obstacle for a group member to work on themselves, a constructive change in themselves (during the game–hot seat psychodrama, lesson 9, a member of the group in the centre of the room with their back to the group, everyone made predictions about what may interfere with work on yourself: "I hope you think about yourself the following...").

Analysis and introspection of psychopictures "Me and our group"; "What the group gave me"; "My strengths and weaknesses"; "My state before the group, my state after the group"; gave a lot of important information in personal changes of the participants, the ability to identify their value orientations, group dynamics, etc.

As an example, let's observe the self-analysis of Iryna's psycho picture "I am before the group activities, I am after the group activities", performed after the ninth training session: "Before the group I felt like a lonely snowdrop which has just broke out of snow and needs warmth. It is cold and lonely. I am unsure of myself (the snowdrop bends to the ground), timid, very anxious. After group activities, my outlook and perception of me and the others changed. I perceive myself as a colourful flower, warmed by the sun. I see other members of the group with the same multi-coloured colours. I am happy with myself and with them. My state of mind is very pleasant (bright, but, "not flashy" but quiet, harmonious with nature). I'm filled with life. I'm thinking optimistically…"

Psycho pictures on the topic "I am real – I am perfect"; and "I am a real student – an ideal teacher"; were informative. The group members compared themselves to animals, plants, geometric shapes, other images: (real – sunflower seeds, perfect – sunflower; real – unripe wormy apple, perfect – ripe red-sided apple; real – cold, shining, not warm, star perfect – the sun; real – a navel punching through the stones; perfect – a blossoming lush rose; real – a spikelet that ripens in the sun; perfect its baked bread; real – a lonely boat that can't swim to the shore; perfect – a fire, torch; real – caterpillar, perfect – butterfly, etc.).

For the formation of sanogenic thinking of future teachers, we used the technique of sanogenic reflection. This method of behavioral correction is based on the change and purification of thinking as the basis of formation of the attitude to a positive attitude to himself and the situation, involves mastering mental operations and introspection skills. The purpose of the method of sanogenic thinking is to desensitize the pathogenic harmful effects of the energy of negative emotions (anger, insults, guilt, feelings of shame, envy, etc.) [15].

We used the teaching method of sanogenic thinking in two aspects: 1) to identify priority habitual stereotypical pathogenic thinking causes deterioration of state of health and health; 2) for the purpose of teaching sanogenic thinking for "healing" of an organism,

formation of a setting for self-creation, self-development with priority of a health-saving strategy of life.

The technique of forming sanogenic thinking can be called auto-psychoanalysis of emotions, which is a catalyst for the transformation of pathogenic thinking into sanogenic. Auto-psychoanalysis exercises of negative emotions, which were performed by members of the training group, training in positive thoughts, images and feelings helped to merge sanogenic thinking as a priority in much behaviour and activity.

Learning objectives of sanogenic thinking include the mastery of introspection to restore the details, circumstances, situations in which future teachers fixed and "deepened" their auto-destructive behaviour. Introspection in conducting sessions of the training group gives a possibility to separate negative emotional reaction from negative habitual patterns of auto-destructive behaviour, which destroy health, to reduce negative emotional response to situational influences. Exercises "Forgiveness"; "Flushing"; "Write the offender unsent letters"; "To caricature the offender"; "A pleasant surprise to their abuser" contribute to the mastering of sanogenic type of thinking, the liberation from age-old grievances and negative emotional states.

The members of the training group performed relaxation exercises aimed at getting rid of negative emotions, relieving emotional stress ("Anti-stress relaxation"; "Stress yourself out of stress"; "Abandoned garden"; "Journey to the bottom of the ocean" etc.). Participants of the training, by mastering and comprehending the negative emotional states that surround them, neutralize their negative emotions, which cause psychological discomfort. Many training members kept diaries in which they recorded self-observation data.

The following methods were used to track the dynamics of the psychological indicators of the occupational health of future teachers who took part in the psycho-pedagogical training: 1) Freiburg personality inventory (FPI) for the diagnosis of the states and characteristics of the personality; 2) the method of "Accumulation of emotional energy charges directed at oneself" to detect the hidden emotional tension of teachers; 3) Questionnaire "The scale of emotional excitability"; 4) C. Spielberger – Y. Hanin questionnaire, designed to assess reactive and personal anxiety; 5) an adapted version of J. Jenkinson's technique for determining stress predisposition) [16-18].

3 Results

We analyzed the effectiveness of the tools we had implemented to correct the occupational health of experimental participants. In particular, the effectiveness of psychological and pedagogical training is presented in Table 1 average group of future teachers' occupational health before and after the training.

Indicators, displayed in Table 1, show the level of relevant qualities' formation and the main psychological indicators of occupational health: emotional states (conflict, balance), personal qualities (irritability, depression, anger, spontaneous and reactive aggression, self-management), anxiety self-control, difficulties in assessing situations). The significant changes in these indicators during the training were assessed using the Student's t-criterion.

Table 1. Comparative analysis of the dynamics of psychological indicators of professional health of future teachers (before and after conducting psycho-pedagogical training).

Methods	Parameters	Before the training	After the training	Student's t- criterion
Freiburg Personality Questionnaire (FPI) for diagnosing conditions and personality traits	I – "neuroticism"	4,29	3,53	3,34**
	II – "spontaneous aggression"	3,09	2,44	2,57*
	III – "depressiveness"	3,53	2,90	2,16*
	IV – "irritability"	4,68	3,53	3,09**
	V – "friendliness"	8,03	8,25	–0,95
	VI – "equilibrium"	7,09	7,75	–2,53*
	VII – "reactive aggressiveness"	3,81	3,31	1,58
	VIII – "shyness"	7,16	6,53	2,26*
	X – "extraversion-introversion"	4,88	4,75	0,38
	XI – "emotional instability"	4,0	3,22	2,60*
	XII – "masculinity-femininity"	3,29	2,97	1,06
Spielberger-Hanin Questionnaire	Personal anxiety	37,31	33,38	3,33**
	Reactive Anxiety	30,78	28,0	2,13*
Emotional Excitability Scale Questionnaire	Emotionality	22,47	19,75	4,82***
	Anger	7,41	6,43	2,06*
	Timidity	9,13	7,94	2.32*
	Lack of control over emotions	6,09	4,71	2,60*
Methodology "Accumulation of emotional and energy charges directed at oneself"	Hidden emotional tension	15,72	13,59	3,90***

Notes: asterisks significant differences:
* – significance level 0.95;
** – significance level 0.99;
*** – significance level 0.999.

The results of the study obtained using the shown in table methods, indicate high rates of neuroticism (anxiety, increased excitability). There are high levels of irritability, which confirm the poor self-regulation of students' mental states, and the level of depression, which is an evidence of a low mood background, immersion in their experiences. Indicators of reactive anxiety of future teachers (prior to participation in the training) show a high level of psychopathization, characterized by painful reaction to criticism and remarks to their address, sometimes manifestations of an aggressive attitude towards the social environment. Low levels of emotional instability and emotionality may be associated with maladaptation, student anxiety, and high levels of frustration.

The results of the use of the Jenkinson method confirmed a high tendency of future teachers to stress (Figure 1). 3 respondents (7,5%) showed a low tendency to stress; 22 respondents (55,0%) had an average tendency to stress; 5 respondents (12,5%) have very high tendency to stress; 7 respondents (17,5%) have a high tendency to stress. Three respondents (7,5%) scored from 13 to 15 points, i.e. they "fell" in the neutral zone of tendency to stress. After the training, the level of future teachers' stress resilience increased.

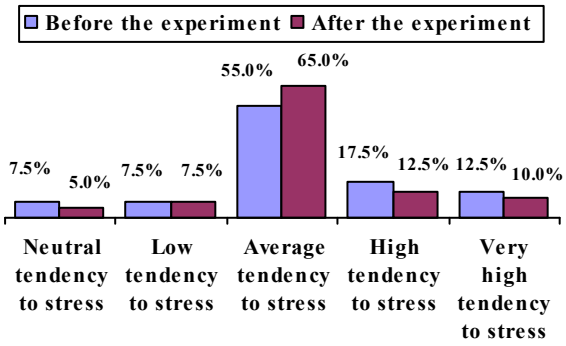

Fig. 1. Distribution of future teachers by level of tendency to stress according to the results of the survey before and after conducting psycho-pedagogical training (in %).

As a result of conducting a psycho-pedagogical training, there have been significant changes in many psychological indicators of the future teachers' occupational health. To test the statistical significance of these changes we used the indicators of future teachers to compare. As the level of subjective control increases in the process of psycho-corrective influence on the individual, we can use it to test the effectiveness of psychological correction methods. The level of subjective control was calculated as the arithmetic way of the scores obtained on the total internality scale. We took into account the dynamics of the group-level indicators of the level of subjective control of the training participants and the control sample. In particular, it was found that the initial states of both samples are characterized by almost identical indicators of the level of subjective control (the difference between them is only 0.006 points. The results of the final diagnostic slice show a high increase in the average group level of subjective control – 0,781 (+0,375) participants training, whereas this indicator for control groups was only 0,464 points (+0,05), and the difference in achievement by this criterion between control and experimental samples was 0,325.

To determine how valid the qualitative differences in the group values of the levels of subjective control of participants of training and control sample at the end of the experiment were, we applied the Student's t-test. The empirical value of the t-criterion (t = 3,7) was compared with the corresponding table value. For the 5% significance level in our case, the t-table is 1,9 – it is much smaller than the empirical value of the t-criterion. Therefore, the differences in the mean values of the level of subjective control of the participants of the training and the control sample at the end of the training are statistically significant. And this confirms the effectiveness of our developed psychological and pedagogical training.

In addition to quantitative analysis of the results of diagnostics, we also carried out their qualitative analysis (research of responses, self-reports of participants of training about their well-being, change of lifestyle or thinking, ways of interacting with others, etc.). The free-form opinions of the trainees provide important material is at least depth, and sometimes more informative, for objective data, limited by diagnostic methods. Here are examples of the following reports:

Sergei: "I learned a lot about myself. There were things I had not realized before. I did not think about the motives of behavior. I realized how important the state of the intellectual-emotional sphere could be for pedagogical activity. The inner tension disappeared (I was especially impressed by the relaxation exercises). Heard a lot of unpleasant information about myself – this is a field for reflection, change of myself. I realized that it was not that easy to forgive, myself and my actions…"

Olga: "I learned to accept myself the way I am. The exercise "Creating ode for the self" helped me a lot. The group opened my eyes – it turns out that I did not know myself well enough, nor did I knew how others perceived me. She became more sincere with people. I want to think and act positively. It is difficult to master the techniques of self-regulation of the inner world, to manage emotions..."

Olesya: "I understood myself and the others better. By understanding ourselves, we can understand others. The group helped me to understand the reasons for the failures, the difficulties in communication. She trusted people became more and more confident. I learned to accept others the way they are. In the group, she experimented with new forms of communicative behavior. There is something to work with. I was aware of this when I was a teacher, a class teacher. It was difficult to restrain yourself, to influence students. I understood what needed to be done in order not to burn in the flames of the profession, to maintain "a good form"..."

The feedback and self-reports of the participants in the training show the positive dynamics of their personal change and are consistent with the results of quantitative analysis of our diagnostic measures. Together, they show significant positive changes to certain experimental indicators that have come about through implementing the tools we have offered to correct the health of the participants.

4 Discussion

The results of the experimental study show the effectiveness of the developed psycho-pedagogical training and the expediency of its introduction into the educational process of higher education institutions for preparing future teachers for the preservation and strengthening of the professional health, formation of the professional stress resistance.

Using psycho-pedagogical training in working with prospective teachers contributes to understand their strengths and weaknesses, identification and change of those traits and behaviours that trigger and support emotional stress (irritability, envy, shyness, vanity, morbid vanity, lack of self-esteem, anxiety, ambition, vindictiveness), the gradual elimination of the neurotic components of their inner world, improvement of interaction with others, coordination of the integral qualities of the person. Psychological intervention work was aimed at elimination or mitigation of such negative manifestations in the teacher's personality as shyness, irritability, aggression, neurotic, depression, affect low resistance to occupational stress. Because of participation in the work of psychological and pedagogical training, the basic psychological indicators of the professional health of future teachers were changed: emotional states (conflict, equilibrium), personal qualities (neuroticism, irritability, depression, anger, spontaneous aggressiveness) and self-regulation of emotional state).

Future teachers, who took part in the work of psychological and pedagogical training, show an increase in the stress resistance level, assertive behaviour, and possession of constructive coping strategies.

5 Conclusions

Teacher's profession is stressogenic, tensed in the psychological terms. An effective way of protection against occupational stress is building up stress resistance at the professional training stage. It is one of the personality traits that ensure that professional stress can be overcome.

Professional stress is interpreted as the ability to withstand stress, negative factors of the pedagogical activity, stressful situations, and the ability to find their own resources in difficult conditions of professional activity. Forming stress resilience for future teachers is associated with finding resources that help overcome the negative effects of stressful situations and eliminate potential sources of stress in their inner world.

An effective means of forming future teachers' professional resilience is the psycho-pedagogical training, which we have developed, is built on the principles of active social and psychological training. The activities of the training group are aimed at the formation of skills of productive interaction and constructive conflict resolution and overcoming the professional difficulties, formation of strategies for protection against stress, teaching methods, and techniques of self-regulation, the formation of sanogenic thinking. Participation in the training group facilitated the mobilization of the personal and neuro-psychic resources of future teachers, and acquisition of subjective self-influence by psychologists.

The dynamics of psychological indicators of the occupational health of future teachers, who took part in the work of psycho-pedagogical training, turned out to be positive and the significant changes were traced.

We see the prospects of further scientific exploration in identifying the possibilities of psychological and pedagogical training in preventing the professional deformations and destructive changes in the teacher's personality in the system of postgraduate pedagogical education.

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Monitoring of the quality of the psychological component of teachers' activity of higher education institutions based on Google Forms

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Abstract. The focus of the current research is on the quality of education as a multifaceted category, and the monitoring of the quality of education – as a purposeful and specially organized system of studying, assessment, analysis of data on the state of education of students. This study aims at exploring the nowadays conditions, and exactly the development of digital technologies. The need of using the electronic resources (Google services) has become more acute, which enables the creation of text documents, presentations, spreadsheets, forms, drawings and other documents. In order to provide the monitoring of the quality of the psychological component of the teachers' activity of higher education institutions the Google form was elaborated to obtain the information about the psychological state and satisfaction of the quality of educational services by the fellows of the educational process, their relationships, socio-psychological climate in higher education institutions and others, and respond in a timely manner to the social and educational changes.

1 Introduction

The quality of education as a key factor in the country's sustainable development plays an important role in creating a single European educational space. The high-quality education itself is an important tool for the creating of the key competences that are significant for the present, the development both of the individual and society, the state as a whole, by ensuring the social and economic growth of the country.

The education right of each individual was regulated by Universal Declaration of Human Rights, and the adoption of the Incheon Declaration "Education-2030: Ensuring of Inclusive and Equitable Quality Education and Lifelong Learning for All" has been set out the fundamental principles for global education development by 2030 [1].

The quality of education is considered to be the heart of education for all [2, pp. 100-109], positively influencing on the changes in student learning (affective, cognitive, and psychomotor domains) and personal and professional potential [3, pp. 3-13]. Hence, the actualization of the monitoring problem of the quality of education in higher education institutions has been being extremely important presently.

The monitoring is an integral part of the management of the quality of education; a means of information diagnosing in the process of carrying the managerial decisions, analysing the educational activities, predicting the changes in the educational process etc. The alteration of the living conditions places the new demands on the quality of education, which requires the study and evaluation of education indicators, the monitoring of the quality of education as a major driver of personal growth and development, as well as the consideration of psychological factors of higher education quality that contribute to the development of the creative and safe environment in higher education institutions [4, pp. 86-89].

The use of information and communication technologies in education creates new opportunities for individualization and differentiation of the educational process, allows you to easily and quickly adapt to the new requirements of the monitoring of the quality of education, ensuring the creation of an optimal environment for educational services, understanding of human behaviour in the social environment, life cycle development and interaction between biological, psychological, socio-structural, economic, political and cultural factors of the educational process [5, pp. 93-104].

The quality of educational process and the effectiveness of the knowledge provided are impossible without diagnostics and monitoring, among which the diagnostic forms are questioning and testing. From this perspective, Google Services attracts our attention as an innovative tool of cloud technology [6, pp. 79-83], which let us control, collect, summarize and analyse the information through questionnaires (surveys) using simple online forms (Google Form), view the

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spreadsheets, and visualize the survey results in graphs and charts for further analysis.

Google Form is utterly convenient tool, the online-service for forming the feedback forms, tests and surveys in order to organize the remote interaction of participants and experts in the framework of the assessment of the quality of higher education.

2 Literature review

The qualities of education as a component of the "Education for All" program is a broad concept and without single interpretation defining its essence, content and components by now, moreover, but as Haddad & Demsky [7], claim, it depends on the policy of the state. Quality education includes: students, educational environment, content, process and results.

The concept "quality" is constantly influenced by economy, politics, culture, so it should be flexible, capable of changing during the evolution of education and progress [8]. For instance, changeability, fairness, efficiency and quality are often used as synonyms [9].

The quality of education as a multifaceted category by its essence covers various aspects (philosophical, pedagogical, psychological, social, economic, etc.). Thus, the quality is understood as the normative level to which the product of enlightenment corresponds [10]; the level of achievement of certain goals and objectives of education, set of indicators characterizing various aspects of the educational process (content of education, forms and methods of teaching, etc.) [11] and others. The quality of education is about the value of education (with reference to its contribution to the learning process and its outcome) [12].

Control and monitoring of the quality of education, continuous monitoring of the educational process in order to identify its compliance with the desired result [13] and determining, where necessary, corrective and developmental measures, are the important tasks of monitoring aimed at the systematic collection, processing, storage and dissemination of information on the state of education, forecasting with reason of objective dynamics data and the main tendencies of its development and science-based recommendations making to take the managerial decisions according to the improving the efficiency of the education industry functioning [14]; the current adjustment of higher education institution's activity [15] etc.

The monitoring of the quality of the teachers' educational activities in higher education institutions in accordance with the public requirements and stakeholders' needs provides a purposeful and specially organized system of continuous (regular and planned) observation (study), measurement, evaluation, analysis of data on various aspects of teachers' professional activity, consequently, the forecasting, the development of science-based recommendations for timely management decisions due to the improving the quality of the educational process and results [16].

3 The monitoring psychological component of the quality of higher education

The Higher education quality as transformative process leads to a focus on psychological factors of quality of higher education which contribute to the development of a creative and safe educational environment [4]. *The psychological component of the monitoring of the quality of education* involves the providing the information about the psychological status and satisfaction with the quality of educational services of the participants of the educational process, their relationship, the socio-psychological climate in higher education institutions, etc.

The criteria of this component are: satisfaction of the requests and needs of the listeners, and indicators: 1) the level of satisfaction of the requests and needs of the listeners; 2) the relevance of the training content to the listeners' professional needs and the stakeholders' requests of as a whole; 3) the listeners' psychological status and level of satisfaction with the quality of educational services; 4) the nature of the relationship between the participants of the educational process and the level of satisfaction with them; 5) the socio-psychological climate in higher education institution as an indicator of the level of development of organizational culture [16, p. 6].

Therefore, it should be indicated, as the educational practice shows, the regular study and the assessment of the data is directly or indirectly carried out mainly by the first three indicators. Hereat, the analysis of data on the relevance of the quality of education to the requests not only of listeners, but also of stakeholders, as a whole, indicates the expediency of intensifying the processes of self-education, self-knowledge and self-development of education workers, improving their qualification. In particular, this is evidenced by the results of a large-scale study made by us during years 2014-2019 (about 1000 respondents from all regions of Ukraine who passed the advanced training at the Central Institute of Postgraduate Education of University of Educational Management) the attitude of the education institutions' employees to their psychological competence, by which the ambivalent character was revealed. In particular, assessing positively the results of the acquisition of psychological competence in higher education institutions, the respondents-educators mainly note its need to influence other participants of the educational process. Simply a small part of the listeners (less than 10%) remarks the expediency of using the acquired knowledge for introspection, reflection of the process of their professional and personal development.

In regards to the indicators "the nature of the relationship between the participants of the educational process and the level of satisfaction with them"; as well as the "the socio-psychological climate as an indicator of the level of development of organizational culture", they were, despite all actuality, practically not monitored. Thus, the psychological component of the monitoring of the quality of education is not fully implemented and

requires the special study, the procedure of which is greatly facilitated by the use of Google services.

4 Google services in the educational activity

It is well known that information and communication technologies are currently considered to be a wide range of digital technologies used to create, transmit, disseminate information and provide services (Internet, e-mail, software, etc.). Google services includes many concepts (infrastructure, platforms, software, data, etc.). The main function of Google services is to meet the users' needs required the remote processing and storage of data [17, pp. 293-306]. Google services is a full-fledged educational tool which enables most effectively to create the own online space and form a personal educational environment for teachers and students of higher education institutions. Google services is a flexible cost-effective model that can be easily and quickly adapted to new software requirements, supporting the standardization of such software and various applications, simplified maintenance through centralized updates. Moreover, they are supported by various devices (tablets, laptops, desktops, etc.) of teachers and students; can be used both in educational institutions and abroad; enable to save time and increase security through the remote control and maintenance, etc. [18, pp. 3-16].

Using Google services enables to develop the digital competency (the ability to consciously and critically use the digital society technologies) [19, pp. 316-336], as well as the information and communication competence as a person's ability to use information and communication technology in practice to meet individual needs and solve the socially significant, in particular, professional tasks in a subject area [20, pp. 226-245].

There are many types of Google services, but in the context of the problem under study we are interested in the service of the Google Drive cloud storage that can help organize the monitoring of the quality of education etc. In order to work with it, the Gmail should be created. The browser-based application is available for free to create any number of Google Forms (web pages) that host a form or a questionnaire. Google Form opens up an extremely wide field of opportunity and creates an opportunity to achieve the stated goal in a short time and collect answers to your questions.

5 The monitoring procedure of the quality of the psychological component of the educational process

Therewith, the improvement of the internal system of the ensuring with the monitoring of the quality of education in higher education institutions, we have compiled a series of express methods (based on Google Form) on the indicators "the nature of the relationship between the participants of the educational process and the level of satisfaction with them", "the socio-psychological climate in higher education institutions as an indicator of the level of development of organizational culture", etc. scientifically-based recommendations for further improvement of the quality of the educational process in the educational institution by the psychological component.

Google Forms permits: to make the questionnaire available to respondents as soon as it is created, upon it can be edited, meanwhile the questions can be opened and analysed; to embed it on a site page, distribute it through mobile networks, where it can be filled by potential respondents; the service automatically to generate a spreadsheet to collect and process the responses to the author of the form, and to display the results of the survey as a spreadsheet (or filtered list) which has all the features and capabilities of a regular Google chart; the service to make it possible to view the answers of all the respondents and separately each of them individually without a spreadsheet, but with the appropriate statistics in the diagrams and graphs data given in qualitative and percentage values formats; to summarize the answers in graphical and numerical format. We have created the form namely "The Quality of the Educational Process: the Psychological Component" containing four techniques. The first method due to the assessment the psychological atmosphere in the unit (team) proposes to choose the opposite by contents pairs of words (by A. Fiedler), which allows describing the nature of interpersonal relationships in the unit [21].

The respondent chooses the correct answer for him/her and puts a mark in each pair (1 to 7), thereby choosing closer to the right or left word, which indicates a more pronounced sign of interpersonal relationships in the unit, such as "agreement" or "disagreement", "satisfaction", "dissatisfaction", etc. (Fig. 1).

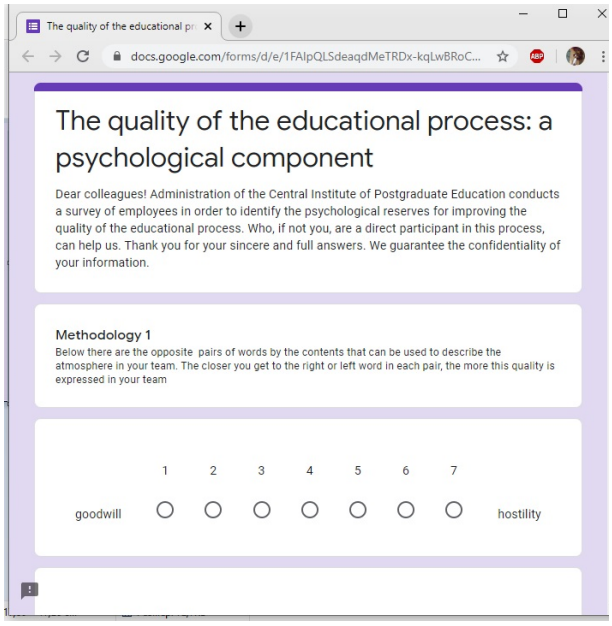

Fig. 1. The interface of Google forms for learning the quality of the educational process.

The screenshot highlights the title of the study "The Quality of the Educational Process: the Psychological

Component", as well as the Method 1 instruction for the respondents to determine the psychological atmosphere in the team.

During the implementation of the second methodology for the diagnosis of psychological atmosphere in a small production group (authors – V. Shpalynskyi, E. Shelest) [21], in the adaptation of O. Bondarchuk), on a 5-point scale, the respondents rate the degree of their favourable climate for the team (goodwill, trusting relationships, joy for success of colleagues, relations with management, adherence to rules in the team, etc.) (Fig. 2).

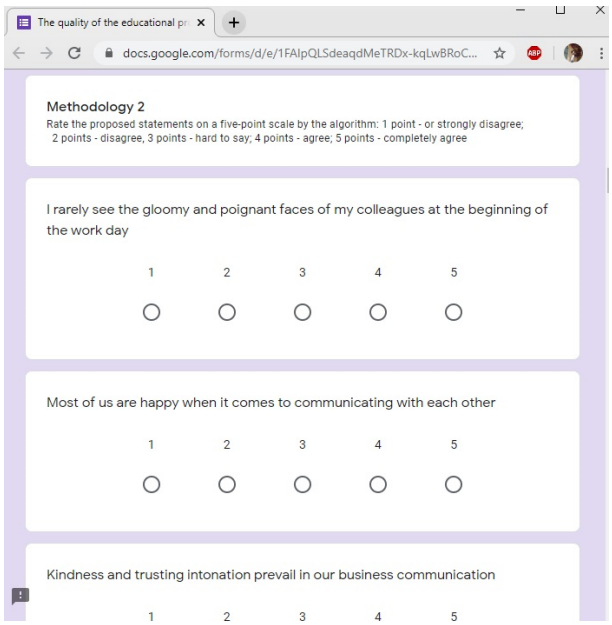

Fig. 2. The interface of Google forms for learning the psychological climate (Method 2).

Referring to Fig. 2, the Method 2 "Rate the proposed statements on the 5-point scale by the algorithm: 1 point – strongly disagree; 2 points – disagree; 3 points – hard to say; 4 points – agree; 5 points – completely agree" is shown on the previous screenshot.

Based on the answers of the respondents, the Google Form gives an opportunity to determine the level of favourable (high, above average, average, below average and unfavourable) psychological climate in the team.

Likewise, the Methods about learning the group cohesion (Sisor Index, adapted by O. Bondarchuk) and the psychological security of the educational environment, allowing determining the level of the psychological security in the educational environment (by I. Baeva, modified by O. Bondarchuk [6, 14-19]), (The Methods 3 and 4 respectively) were applied.

After filling in the Google Form, the respondent must click the button "Submit" (Fig. 3).

Referring to Fig. 3, the screenshot shows the option of choosing the answers for the employee's protection "From the unfriendly attitude of the administration" and "How satisfied are you with your life as a whole?". The "Submit" function is visible at the end.

After receiving the answers, we are able to review them, create a spreadsheet or chart where it is possible to examine the statistics for each question, analyse appropriately, evaluate etc. The results of the answers can be obtained in the form of the linear scale Fig. 4 or diagrams Fig. 5.

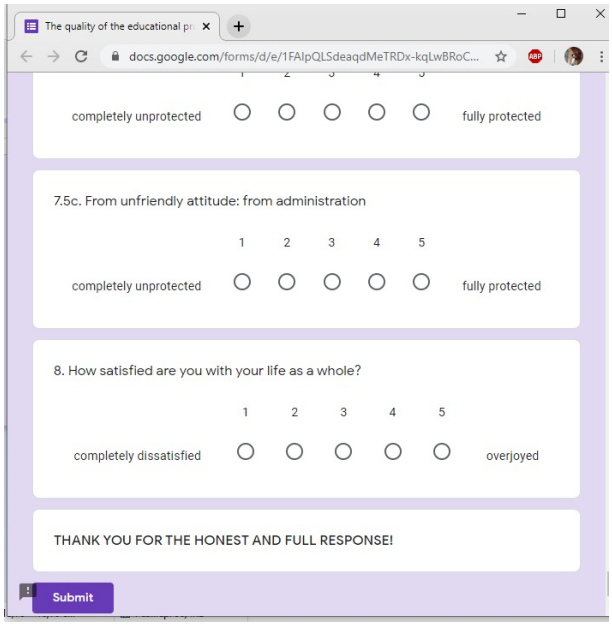

Fig. 3. The interface of the "Submit" function.

The example of the analysis of the answers in the form of the linear scale to the question "Would you go to another unit if this opportunity happened (without changing other conditions)?" and "What are the relationships between the members of your unit?" is given in Fig. 4.

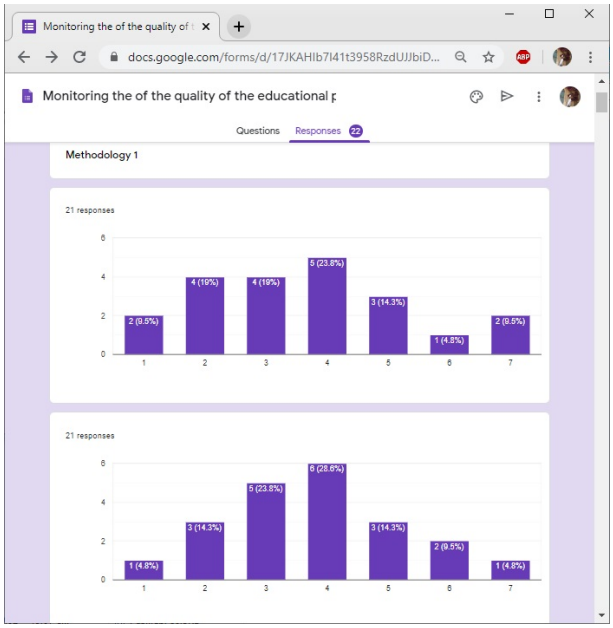

Fig. 4. The statistical analysis of the answers to the questions in the form of the linear scale.

The results of the study provide the following answers to the question – "yes, I would strongly like to move", "I do not know, it is hard to say", "would rather move than stay", "see no difference", "most likely would stay in to my unit", "would strongly like to stay in my

unit".

The analysis of the results enables to make a deep analysis of the psychological conditions, as well as facilitate the development of recommendations, programs for improving the social and psychological climate in the educational institution.

Thus, in particular, the analysis of the results of the pilot survey of the Yuriy Fedkovych Chernivtsi National University teachers, the case of which is given in Fig. 5, allows to conclude about the significant problems of the psychological assurance of the quality of education, nevertheless, as it is seen from the figure, just 47,8 % of teachers consider the relations in the team as favourable. 25% of respondents would change the jobs. It is quite problematic to provide a student-centred approach to the organization of the educational process in such situation. Accordingly, it is urgent to develop the special psychological and managerial measures to minimize the revealed negative tendencies in the activity and interaction of higher education institutions teachers.

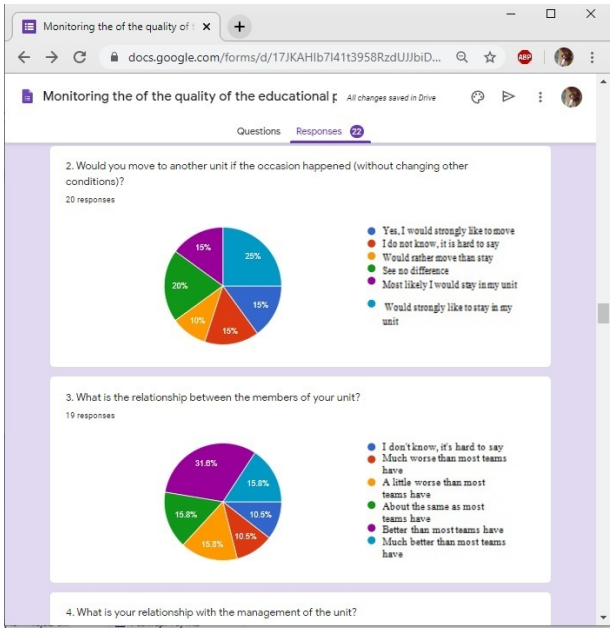

Fig. 5. The statistical analysis of the answers to the questions in the form of diagrams.

6 Appraisal of Google Forms as a tool for monitoring the quality of education

The monitoring of the quality of education with Google Form enables swiftly to get the feedback from the participants of the educational process on the quality and outcomes of the educational activity. This is evidenced, in particular, by the validation of the Google Forms created in the pilot study, which confirmed the efficiency in obtaining information, analysing the quality and percentage values in graphical and numerical format, reaching a large number of participants in a short time.

It is noteworthy, that the data from a Google Forms spreadsheet is easily imported into other spreadsheets (including SPSS) with aim of in-depth processing of results using factor, cluster or regression procedures and other kinds of statistical analysis.

Based on the evaluation of the monitoring results of the quality of education, a set of corrective and developmental measures is determined in accordance with the conceptual goals and objectives of the functioning and transformation of the educational system presently [21].

Consequently, the usage of Google services, the Google Form notably, contributes to the improvement of the internal system of the ensuring the monitoring of the quality of education, the development of science-based recommendations for the further improvement of the quality of education in higher education institutions with the psychological component, and furthermore, the improvement the competitiveness and attractiveness of educational institutions in regard to the analysis of their resources.

The documents and spreadsheets, created by using Google services, are stored on a cloud server (or can be saved to a file) [23], which is one of the key benefits of the program, since the access to the given data may be entered from any computer or mobile phone connected to the Internet.

Furthermore, the obtained resources can be used to adjust the management system in the educational institutions, managing goals, vision, mission, the educational environment [24], as well as to increase motivation and efficiency [25], to train a person to learn and apply modern international relations.

Conclusions

The authors described studies related to the efficiency monitoring improving of the quality of the psychological component of education through the implementation of information and communication technology to education, namely Google services, basing upon on the latest achievements and results of advanced research in the relevant fields. Google services opens up an extremely wide field of possibilities, enables to create text documents, presentations, spreadsheets, forms, drawings and other documents.

The monitoring organization of the quality of the psychological component of education with Google Form makes it possible not only to determine the nature of the relationship between the participants of the educational process and the level of satisfaction with them, the peculiarities of the socio-psychological climate as the level of development indicator of organizational culture, but also to make appropriate managerial decisions and forecast the situations in the educational environment; to promptly intervene and make appropriate adjustments to the educational process; to specifically plan the work on the relevant problem in higher education institutions; to create conditions for comparison of own assessment of pedagogical staff activity with independent assessment.

Thuswise, there is an urgent need to develop a reliable and valid toolkit for holistic and prompt monitoring of the quality of education using the Google services, not only on the psychological component, but

also on all the criteria and indicators of the quality of higher education, which determines the prospects for further work.

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The peculiarities of using the computer complex HC-psychotests in the process of psychodiagnosis of the level of development of future specialists' mental capacity

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Abstract. The IT revolution, which has embraced material production, social relations and the whole sphere of culture and education, is more and more contributing to solving the problem of automation of intellectual processes in science, technology and society, as well. This scientific article is devoted to the consideration of topical issues of introduction of the computer complex HC-psychotests in the process of psychological support of professional-personal development of the future specialist during the period of study in high school. The article also presents the analysis of the versatile possibilities of using the NS-psychotest in the paradigm of modern education. In this scientific article, the results of the screening study with the use of HC-psychotest in the process of psychodiagnosis of the level of development of mental capacity of future specialists are analyzed in detail. It is determined that the complex HC-psychotests allowed to give multilevel, multiparametric characteristics of the mental states of the respondents with the use of psychological, psychophysiological, physiological and social indicators. It has been proved that the introduction of computer psychodiagnostics has not only enriched the experimental base with appropriate methods that facilitate the implementation of various research strategies, but also combined empirical work into a single technological cycle.

1 Introduction

Nowadays, a new paradigm of cultural and educational space is being formed all over the world, within the framework of higher education, which is focused on joining the world information in educational and communicative space. Such a system leads to changes in the educational process, which must be in line with current technical capabilities and promote the harmonious adaptation of the future specialist in the information society. Computer technologies are aimed at increasing the efficiency of the educational process. Modern information computer technologies (ICT) are increasingly being introduced into various spheres of life, becoming an integral part of human existence and modern culture. ICTs enable automation of such information processes as: long-term and compact storaging, searching, processing, and producing of new, transmitting at any distance and presenting multimedia (text, spreadsheet, graphic, animated, audio and video) information.

The Concept of Higher Education Modernization has the important task of mastering the ICT skills by a modern person. Due to the change of professional activity dominant, it is necessary to prepare future specialists for various types of activities that are related to information processing, including the development of informatization tools. The introduction of modern information technology training has to be gradual: from the use of some elements of ICT training to the use of electronic textbooks [1].

The introduction of digital technologies in education creates a fundamentally new communicative environment, which requires a future specialist not only to have the ability to work with digital information, but also to possess "soft skills" – abilities to search and work with information, interpersonal communication, teamwork, flexible and creative thinking.

The global reformation process determines the relevance of introducing innovative ICT technologies into the educational environment. One of the directions of development of sustainable higher education is the development of a competitive specialist. In this regard, the four dominant competencies of a modern specialist are identified, which determine the success of professional tasks:

• Critical Thinking – Considered fundamental to the 21st century learning, critical thinking involves accessing, analysing and synthesising information in a way that helps learners evaluate ideas and make decisions.

• Communication – it is more important than ever to be able to communicate effectively and have the capacity to express thoughts clearly and persuasively in the workplace and public. Communication skills are embedded in information, media and ICT competencies

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and will be more and more essential for employers and societal progress in the 21st century.

• Collaboration – Collaboration and teamwork are highlighted as a critical area for development both in and outside of school. It is an essential skill for working in the 21st century as 'local' takes on a new meaning.

• Creativity – Creativity and innovation will be in the forefront of our educational systems, like the ability to "break new ground", invoke fresh ways of thinking, put forth new ideas and solutions, pose unfamiliar questions, and arrive at unexpected answers will become crucial skills.

There are the following main areas of introduction of computer technology in the educational process: the use of computer technology as a means of learning; the use of computer technologies as a tool for learning about yourself and environment; consideration of computers and other modern information technology tools as objects of study; the use of new information technologies as a means of creative personal development; the use of computer technology as a means of automating the processes of monitoring, correction, testing and psychodiagnostics; organization of cooperation using information technology tools for the purpose of transferring and acquiring pedagogical experience, methodological and educational literature; the use of modern information technologies for the organization of intellectual leisure; intensification and improvement of the educational institution management and the process of education [2].

According to researchers, the number of students in our country who are able to use the computer and the Internet resources in various ways, has increased about 10 times during last 5 years. However, it is considered that they spend more time communicating on social networks and entertainment sites. At the same time, the cognitive motives, self-knowledge and self-development in the process of working with a computer and the Internet network are at about the 20th place. Simultaneously, the issue of training a competitive specialist, capable for constructively solving professional tasks in a changing living space and maintaining a high level of professional stability and efficiency, is urgent for modern higher education. Preparing young people for life and activity in a competitive and dynamic world requires professional and personal growth of the participants of the training process [3]. All this actualizes the problem of psychological support for the process of vocational training in vocational education institutions, its focus on students' personal and professional growth, the development of their ability to adapt quickly to the new conditions, to respond to new challenges, to develop democratic partnerships and interpersonal communication, in order to be an active participant of community.

The use of innovative ICTs in the process of psychological support for the professional development of future professionals is becoming a priority area of professional education.

2 The main possibilities of using ICT in modern psychodiagnostics and educational practice

The use of psychodiagnostics capabilities of modern computers to store compactly, to retrieve quickly and to display information clearly has certain benefits:

1. Versatility of equipment. A personal computer, by its functionality, can replace a whole set of devices and allow you to connect additional equipment if necessary. Computing standards allow the developer to focus on the methodical side of the test being created, which can be used on any personal computer.
2. Ability to generate tasks. In psychodiagnosis, the problem of adapting the respondent to stimulus material (e.g., to numerical tables) is an urgent one. The ability to generate test tasks allows you to create a large number of different tasks, to enter into the process of research trial (training) attempts and to use diagnostic techniques as simulators for the development of mental qualities.
3. Setting up experimental conditions. Managing the program settings opens wide opportunities for adjusting the conditions of the experiment. You can change the colour, shape and size of objects, exposure time and pauses, sound effects, etc. This makes it possible to create levels of complexity by adapting the methodology to a different contingent of respondents.
4. Test automation and standardization. The software implementation of the diagnostic methodology requires a specific algorithm that can provide a certain sequence of tests, depending on the results obtained. This creates test batteries and incentive simulators.
5. Ability to create new techniques using animation. The ability to depict objects in motion allows you to create new, more effective diagnostic and developmental techniques. The basis of such techniques is the modeling of dynamic processes and the involvement of the respondent directly in the development of the situation. Great prospects are opening up to the techniques implemented in the game form. The game (competitive) form of the test significantly changes the perception of the task, the respondent's motivation, attitude to the result.
6. Possibility of fixing additional parameters. In the computer implementation of diagnostic methods, when the entire process of testing is controlled by the program, it may be possible to fix additional parameters that extend the complex characteristics of the investigated mental phenomenon. For example, fixing the time of a single move in multi-pass manipulation and form tests allows you to study the dynamics of attention in the process of completing the task.
7. Online data processing. Test automation allows you to transfer all routine work to your computer, including mathematical and statistical processing of the data obtained. The high speed of computer calculation makes it possible to use methods that were previously little used due to their complexity (regression, variance, factor analysis, etc.) for data processing. Operative processing allows not only to evaluate the obtained results, but also to simulate other options for studying

what is relevant in the study of compensatory mechanisms, mutual influence of mental processes, relationships in the group [4].

8. Enhanced results delivery. It is difficult to overestimate the value of presenting research results for their correct interpretation, and the personal computer provides virtually unlimited possibilities. The use of color, font, graphics, sound and animation allows to maximize the features of the results of the study. There are two types of automated psychodiagnostic findings. The first is aimed at for the respondent, and the second - at the professional psychodiagnosis. These two types of interpretation should not be identical. Testimonials should primarily be formulated in a language of life psychology adapted for non-professional understanding. At the same time, "rapid interpretation is expected by the patient with impatience and increases his interest and motivational involvement in the survey" [4].

9. Increased standardization and validation. The use of computers helps to increase the level of standardization of conditions by equally instructing the respondents and by presenting tasks that do not depend on the sex, age, degree of attractiveness and mood of both the experimenter and the respondent. In addition, the privacy of an automated survey allows the respondent to be more forthright and natural during the research.

In addition to computer's benefits, the psychologist, according to Duke, is presented with qualitatively new opportunities to organize a computer psychodiagnostic examination.

1. Dynamic and polymodal stimulation. On the screen of a modern computer, it is possible to depict dynamic objects by means of computer graphics, which brings the model activity from the test execution to the real activity for which the test is intended [3]. The possibility of polymodal stimulation as a combination of its visual and auditory form is also of great importance.

2. Alternative order of test incentives. The simplest way of realizing this opportunity is to organize randomly the stimulus sequence. This principle also provides on adaptive testing, in which the sequence of presented tasks depends on the results of its responses to previous incentives. As a result, many of the respondent's tasks in the multistage testing process may not maintain the diagnostic capacity of the whole test. Due to the adaptive approach, it is possible to reduce significantly the complexity and time of testing.

3. Time as a factor in psychodiagnostics examination. With the help of a computer, a psychologist is able to adjust and set the required rate of psychodiagnostic testing. This rate can also be adjusted automatically, without the direct involvement of a psyhodiagnosis. On the other hand, time can serve as a diagnostic parameter, for example, as an indicator of the temporal dynamics of the answers to the test question.

4. Complex information processing algorithms. A wide range of various laborious procedures for calculating scales, indexes, auxiliary indicators, for carrying out diagnostic analysis related to finding precedents in a data bank, etc. has become possible.

5. Bank of psychodiagnostics data. Maintaining a data bank in which the results of psychodiagnostic research are accumulated can accelerate significantly the process of obtaining reliable, empirically substantiated test standards for the different contingents of respondents.

6. Game motivation. The "inclusion" of game motivation increases the attractiveness of the testing process and increases the reliability of the results. With the help of computer games, you can simulate certain activities. In the computer psychodiagnostic game, there is a possibility to combine verbal and nonverbal stimuli. On the one hand, a computer game is able to combine the functions of questionnaires and criterion-oriented performance tests. Complex KIM-88 – "complex game techniques" [5] – can serve as an example of this computer psychodiagnostics direction.

7. Display results. With the help of displaying information on modern computers it is possible to arrange the issuance of psychodiagnostic examination results on the screen or in the form of a profile of a person, graph or table, as well as the results of a survey towards the sample of respondents with the help of diagrams and histograms of the distribution of values of a given psychodiagnostic index. It is also possible to convert information using scaling methods and display the results of multivariate tests into two- and three-dimensional pictures, which allow you to evaluate the groupings of the surveyed in the space of a multidimensional technique.

8. Intelligent interface. It is the possibility to receive various information, explanations, recommendations on preparation of psychodiagnostic examination and in the process of conducting it through a computer dialogue, as well as to draw a substantiated psycho-diagnostic conclusion in a comprehensive form [6].

3 HC-psychotest is an innovative psychodiagnostic computer complex

Rapid updating of information in all areas of knowledge challenges modern university with the most important tasks to prepare students who are able to be competent in modern society, who should manifest themselves in the following:

• the ability to adapt to rapidly changing conditions;
• to think independently and make decisions necessary for successful performance;
• to work competently with information, extract and process it, as well as to use effectively information resources, including global ones, to solve urgent problems of creating a sustainable education in a developing information space.

The priority perspectives of using innovative computer technologies in psychodiagnostic practice made it possible to open the laboratory of psychophysiological research at Bogdan Khmelnytsky Melitopol State Pedagogical University, which is equipped with the newest computer complex for psychotherapy. The relevance of using the HC-psychotest computer complex in the process of ensuring

the sustainable development of higher education is due to the need to build an individual vector of professional and personal development of a future specialist taking into account individual psychophysiological indicators, level of performance, professional stability and professional orientation.

The use of the innovative HC-psychotest complex in the framework of modern higher education is focused on the implementation of the following functions: educational, research, diagnostic, correctional and developmental. The following are a number of significant advantages of using this computer complex in the modern educational process (Fig. 1):

1. The computer complex significantly expands the possibilities of providing educational information. The use of color, graphics, sound, all modern means of video technology allows you to recreate a real atmosphere of activity.

2. HC-psychotest can significantly increase student motivation to learn. Motivation is enhanced by the interconnection of theoretical foundations and the realities of practice.

3. The computer complex involves students in the educational process, contributes to the widest possible disclosure of their abilities, increases mental activity.

4. The use of this complex in the educational process increases the possibilities of setting educational tasks and managing the process of solving them. Computers allow you to build and analyze models of various objects, situations, phenomena.

5. This computer complex allows you to qualitatively monitor the activities of students, their activity and performance, while ensuring the flexibility of managing the educational process.

6. HC-psychotest allows students to diagnose the level of reflection and self-reflection, which is professionally important for the activities of future psychologists. The program allows students to visualize the result of their actions, to determine the stages of problem solution.

7. Based on the data obtained as a result of the integrated use of the HC-psychotest, it is possible to build an individual trajectory of training and professional development of future specialists.

As part of the implementation of the educational function and the actualization of the research potential of future specialists the HC-psychotest in the Laboratory of Psychophysiological Research is used in the following areas of activity:

- the use of graphic, video and audio elements for the integrated assimilation of educational material by future specialists and the implementation of an individual approach in the process of training students with special educational needs;
- the formation of practical skills of self-building an individual psychodiagnostics research program taking into account age-related characteristics and respondents' requests;
- in the process of studying psychological disciplines (for example, developmental psychology, experimental psychology, clinical psychology, political psychology, etc.), students solve practical competence-oriented tasks, cases, which ensures the internalization of theoretical knowledge and practical skills;
- in the process of studying the educational discipline "Psychodiagnostics", the development of practical skills in planning, conducting psycho-diagnostic research, collecting primary psycho-diagnostic data, compiling a protocol for psycho-diagnostic research, compiling a psychological portrait of a person and analyzing group processes based on the use of computer technology;
- in the process of studying the discipline "Mathematical Methods in Psychology", students use computer software to systematize and mathematically process psychodiagnostics data;
- the use of computer support in the process of monitoring the level of students' knowledge and analysis of educational effectiveness;
- in the process of implementing individual research activities, students have the opportunity to carry out virtual modeling of mental processes and phenomena, compiling a comprehensive psychodiagnostics program, planning an empirical study, implementing a program and strategy for empirical research – individual, intragroup or intergroup, mathematical processing of data, establishing correlation dependencies between variables, graphical and integrated presentation of the result own research.

In the process of implementing the diagnostic and correctional-developing function, the HC-psychotest is used in the following areas of activity:

- providing individual and group psychodiagnostics activities as a component of psychological support for students in the modern educational information environment;
- based on psychodiagnostics data, the construction of an individual vector of professional and personal development of future specialists in accordance with the requirements of the profession and student-centered strategy for the development of sustainable higher education;
- based on the results of psychodiagnostics, taking into account the individual psychophysiological characteristics of future specialists, the development of an individual strategy for teaching and developing students in order to improve the quality of professional education;
- development and testing of psychological correctional and developmental programs of the individual vector of professional and personal development of the personality.

Accordingly, the relevance of using this computer software is due to the following properties:

• the ability to optimize the continuous educational process of the individual (the ability to individually plan the place, time and pace of the educational process based on the results of psycho-diagnostic research and the construction of the vector of individual professional development);

• the opportunity to provide prospects for acquiring a new or related career in a short time;

• the adaptability of information technology training to individual psychophysiological characteristics of the student.

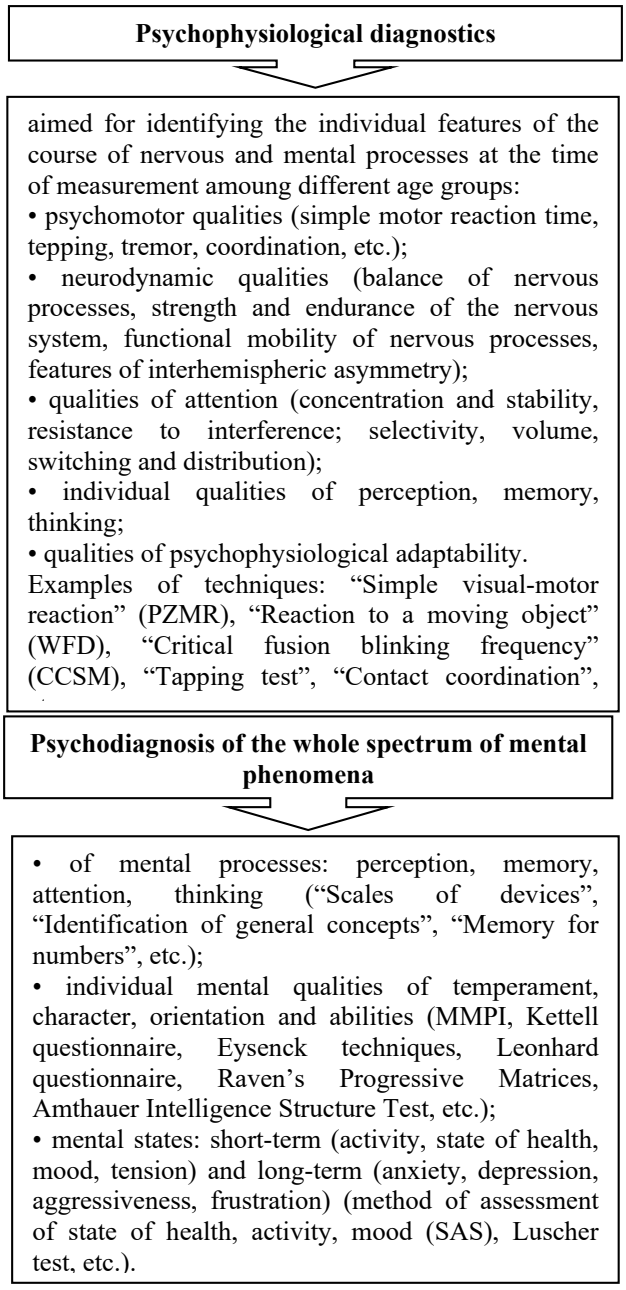

Fig. 1. The possibilities of using HC-psychotest in the area of higher education.

In the Laboratory of Psychophysiological Research, scientists use the following equipment of the HC-Psychotest to solve questions of psychological support of future specialists:

1. Implement "Expert". A complete set that can be used in any psychophysiological study to assess the functional status and limitations of life on the basis of mental and physiological indicators, taking into account personal characteristics. The use of a polyregger allows to analyze the autonomic and emotional reactions during testing. This makes it possible to make a conclusion based on the physiological cost of the activity performed. A complete set of clinical questionnaires, techniques, and devices allow you to assess the level of adaptive capacity to neurodevelopmental stress. The state of the CNS and the regulation of the cardiovascular and respiratory systems are evaluated.

2. Implement "Candidate". An effective and easy-to-use tool is used for career guidance and selection of candidates for vacant positions regardless of their work experience. The "Candidate" gives an opportunity to evaluate the level of expression of professionally important psycho-physiological qualities and professional competences, as well as to predict the further development of a specialist and to conduct in-depth professional psychodiagnosis. An HR professional can use the results of research for understanding the strengths and weaknesses of a candidate, can make a decision about the feasibility of offering specific vacancies, can evaluate the limitations of future activity, or provide recommendations for developing an employee's potential.

3. Implement "Childhood". This set contains methods for psychological testing of children and adolescents. A block of projective techniques has been developed for preschoolers to assess their emotional state, level of school readiness, peculiarities of relationships in the family. For children of primary and secondary school age, a wide range of test materials is provided to study the features of cognitive functions, reactions to various activities, and the level of neuroticism. For high school students there is a career guidance block that helps to select the sphere of future activity according to psychotypes and personal qualities.

4. Implement "Sport" is a special set of tests, which allows to evaluate complexly important for sports activity psychophysiological and mental properties of the body: functional asymmetries of the person, personal anxiety, resistance to stress factors. Thanks to this equipment, the laboratory staff assesses the functional status of the athlete, his readiness to perform (play). Timely diagnosis of overtraining and detection of the initial stages of the disease is the main strategy of the set "Sport".

5. Implement "Start" is used in screening psychophysiological researches and gives an opportunity to investigate such issues as properties and states of personality; disorders of various mental functions; temperament and mental stability, interaction of personality and a group.

4 The use of hardware devices in the process of psychodiagnostics

For conducting psychophysiological tests, scientists at the Laboratory of Psychophysiological Research have the following hardware devices (Fig. 2):

1. Schulte Tables (Diagnosis of Attention Properties) is one of the most popular tests for assessing volume, distribution, and speed of switching attention. It is constantly used in professional selection in specialties requiring high concentration of attention. The test is performed on a special keyboard or using a touch screen.

2. Diagnosis of visual-motor reactions. Assessment of visual reactions has a key place in psychophysiology. The essence of the study is to measure the time of the motor response to the light stimulus. Analysis of the obtained results allows us to estimate the absolute time,

stability, stability of the reaction, the probability of errors and failures. Accompanying indicators show the operator's readiness for work, the degree of his stress and fatigue.

3. Diagnosis of the strength of nervous processes. With the help of a tepping-test sensor, it is possible to determine lability and endurance of nervous processes, general human performance, resistance to monotonous activity, development of volitional personality qualities and other indicators of higher nervous activity in a matter of seconds.

4. Diagnosis of accuracy of movements. The coordinator is designed to evaluate tremor of the upper extremities at rest and during arbitrary movements.

5. Diagnosis of a pulse wave. The use of a miniature pulse-symmetric sensor allows you to determine the heart rate and SpO2 index.

6. The polyregistrator. To determine the level of adaptive capacity of the person for mental stress and to measure the physiological cost of the activity, a miniature device – a polyregistrator, was developed. It is capable of recording physiological parameters by means of three methods: ECG, oral pole muscle EMG, and pneumogram.

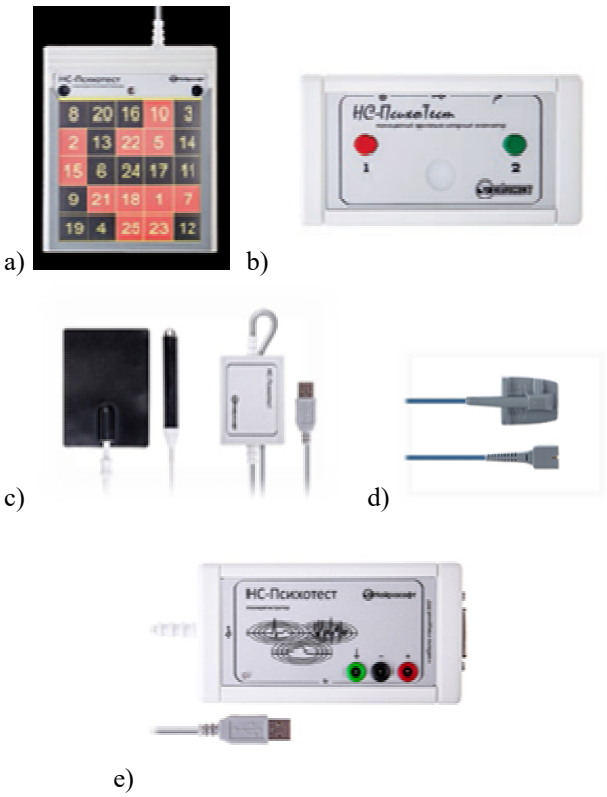

Fig. 2. Hardware devices of the HC-psychotest (a) Schulte Tables; b) visual motor reaction recorder; c) tepping-test sensor; d) coordinator; e) polyregistrator).

5 An empirical study of the level of development of mental abilities of a person using HC-psychotest

As part of the scientific activity of the Laboratory of Psychophysiological Research in 2019, the staff conducted a screening computer psychodiagnostics study of the psychological features of students' mental performance. The ascertainment experiment, which was conducted during 2019 (Fig. 1), involved the first year students of Bogdan Khmelnitsky Melitopol State Pedagogical University (the total number of respondents was 162 people aged 17-22). The sample is representative. The sample was formed by the stratification method. All subjects were divided into subgroups of 10 people. In the diagnostic procedure, each student took an average of about one hour. A certificate of conformity No. PR.871-20 issued by the Ukrainian Scientific Certification Institute confirms reliability, validity, representativeness of psychodiagnostics techniques in the HC-psychotest computer complex. Also, using this computer complex, statistical processing of the obtained data was carried out. Computer processing of the results of psychodiagnostics studies, automatic execution of research protocols made it possible to significantly reduce the procedure for diagnosis and mathematical data processing.

According to scientists, mental work is characterized first of all by emotional tension. At the same time favorable emotional states, which systematically support the functional activity of other mental processes are the leading ones. According to the results of modern research, emotional processes directly regulate the mental capacity of the individual, maintain a certain level of mental activity [7]. Depending on the effect that the state of tension has on the efficiency of activity, states of operational and emotional tension are distinguished. Operating tensions are dominated by procedural motives, so it has a positive effect on the subject and maintains a high level of performance. Emotional tension is characterized by a pronounced negative affective color of behavior, the destruction of the motivational structure of mental activity, as a result, its effectiveness decreases [8]. It should be noted that in modern conditions the increase of emotional intensity and intensity of work, when various emotional stresses begin to act with great force on a person, many problems, related to the decrease of the level of intelligence, deterioration of emotional state and reduction of personality stress has arosed [8]. Personal emotions which are accumulated under the influence of powerful intellectual load reduce the level of respondent's mental capacity. Such stressful condition of the person is at the same time the cause and consequence of the occurrence of chronic fatigue in it [9].

The student's orientation as a subject to the knowledge of their own mental life is the epistemological aspect of the subject of psychology and an important educational aspect of the work of any teacher in the university, which is a real subject of pedagogical activity [10]. So, in ordering the theoretical achievements of scientists, based on the analysis and generalization of the scientific foundation, we have identified 4 basic criteria of mental capacity:

1) The cognitive component is the development of cognitive processes (the level of functioning of cognitive processes of the individual, the ability to perceive and

select information according to the purpose of mental activity, to highlight the main, analyze, compare work, argue their thoughts and actions, memorize the necessary material);

2) The emotional component is an emotional-motivational activity to intellectual actions (striving for cognition, initiative in performing intellectual tasks while maintaining emotional stability, activity and productivity of activity);

3) Personal component – subjectivity, objectivity, regulation of mental activity (the ability of the individuals to initiate, to perform mental activity independently and persistently, to evaluate it independently and critically and to take responsibility for their actions) [11];

4 The connective component is the performance of intellectual activity (a display of the completion of mental activity and orientation for the performance of intellectual activity).

On this basis, the mental capacity of the first-year student is considered by us as the integrative capacity of their personality to perform purposeful intellectual activity, which is ensured by the development of cognitive processes, emotional-motivational activity, as well as by their subjectivity, objectivity in activity.

Based on the results of theoretical and methodological analysis of the problem of research future specialists' mental capacity, we have developed a scheme of empirical research using the HC-psychotest:

1. In the first stage of the study, a comprehensive research program, focusing on the identified tasks of the work was developed.

2. At the second stage of the experiment, which was aimed to obtain data on the psychological characteristics of students' mental performance by its main components, a study was conducted at the Bogdan Khmelnitsky Melitopol State Pedagogical University.

In order to identify the psychological features of students' mental performance (focusing on certain basic criteria and components of mental performance), we applied the following group of techniques. To study *the cognitive component of mental performance*, which is presented by the development of students' cognitive processes, we have used the following techniques:

- The technique "Evaluation of attention selectivity" was chosen by us as a diagnostic material on the basis that a large amount of educational and scientific information requires students to be able to isolate objects on essential and insignificant grounds, to summarize them and to organize them.
- The state of optimum mental capacity is not possible without stability of attention. In order to identify the level of stability of students' attention in the course of the study, we used the method "Corrective test".
- The methodology "Analytical thinking research". The purpose of the study is to determine the level of development of analytic inductive thinking of students in a limited time. Analyticity is an important characteristic of thinking, in this case, we mean, the inductive thinking and the ability to operate (numbers).

The technique "The amount of short-term memory research", was aimed to determining the amount of students' short-term memory. The ability to retain and reproduce information quickly is of great importance for a successful university learning process.

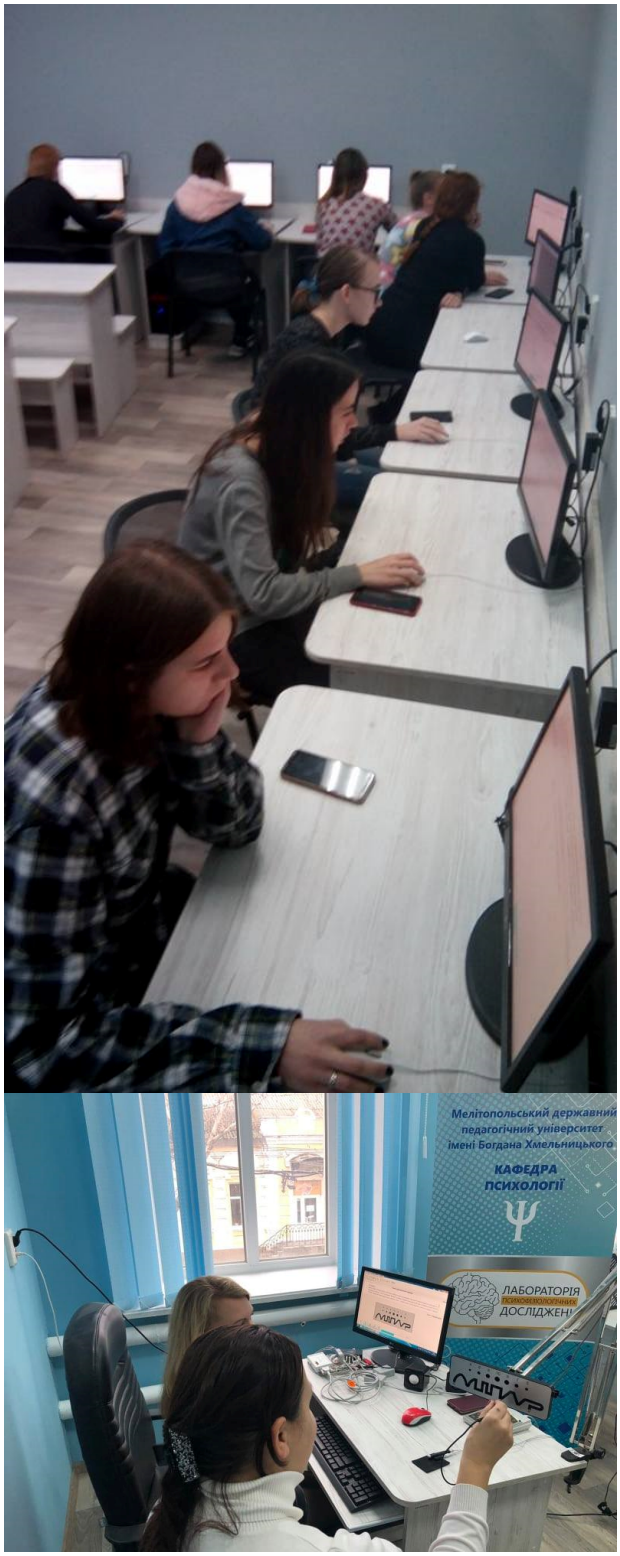

Fig. 3. Conducting a psychodiagnostics study using HC-psychotest.

In order to study *the emotional component of mental performance*, the method "Questionnaire DORS. Differentiated assessment of states of reduced performance (fatigue-monotony-supersaturation-stress),

which is aimed at determining the degree of manifestation of each of the states of performance (fatigue-monotony-intersection-stress) was implemented. The development of these states leads not only to a decrease in mental performance, but also affects the qualitative characteristics of behavior and emotional coloring of experiences, which provokes significant changes in the motivational sphere of the individual [12].

In order to study *the personality component of mental performance*, we used the questionnaire "Autonomy-dependence of personality in educational activities" [13]. The questionnaire allows you to determine the ability to exercise autonomy through the mental performance, to evaluate critically person's intellectual activity, to execute it persistently.

The connective component of the mental performance of first-year students was studied by us on the basis of the analysis of their academic performance according to the results of the exam. At the same time, the indicators of absolute success, quality of knowledge, completeness of mental actions and levels of students' performance of intellectual activity were taken into account [12, 13].

According to the results of research of *the cognitive component* of mental capacity, indicators of the development of students' cognitive processes are revealed. The results obtained are presented in table 1.

Table 1. Quantitative indicators (%) of levels of development of the cognitive component first year students' mental capacity.

Cognitive processes development levels	Attention selectivity	Attention persistence	Analytical thinking	Short-term attention volume
high	29.47	9.12	17.90	11.93
medium	43.85	52.63	61.05	69.12
low	26.68	38.25	21.05	18.95

Taking into account the indicators of the level of attention selectivity (method "Assessment of attention selectivity"), 43.85% of students has a medium level of attention selectivity development, which indicates their ability to select meaningful information and ignore irrelevant and indirect ones, to identify items on essential and non-essential features, to summarize them partially and to schematize them, this slightly reduces their level of intellectual and cognitive activity. 29.47% of the respondents are dominated by the high level of development. They have demonstrated the ability to distinguish objects by their essential properties, to summarize them and to schematize them, as well as their ability to find undivided images in the background. These are those first-year students who have accomplished the task quite well and have performed sufficiently intellectual exercises that require the use of this attention peculiarity.

But there were also students who have shown a low attention rate (26.68%). They may not always be able to choose what is needed from the material they are offered, they can only allocate items on irrelevant grounds, and therefore will have some problems performing intellectual tasks. This result may be related to a state of intense emotional experience and external obstacles that led to the frustration of the respondent.

After processing the data of the method "Corrective test" results regarding the level of development of attention stability of first-year students were obtained (see table 2).

Table 2. Levels of development and indicators of students' mental capacity.

Levels	Indicators
High	Students are able to distinguish subjects on essential features, are able to generalize and schematize them, maintain high intensity of attention for a long time even in adverse conditions of activity, use logic in the analysis and decision of intellectual tasks, demonstrate prompt retention and reproduction of information. Fatigue has a short and temporary nature, motivated to perform uninteresting mental activity, students do not seek to stop it, no manifestations of stress. First-year students are independent in their mental activity, assess critically their intellectual activity, are persistent in its implementation. They display special creative abilities while exercising mental actions, have the ability to complete thinking tasks.
Medium	Students are able to distinguish on both essential and irrelevant grounds of subjects, they can partially summarize and schematize them, while keeping motivated attention on an interesting subject, use logical conclusions in the conditions of attractiveness of intellectual activity, more often memorize and restore distinctive features. They have a slight decrease in endurance, the performance of intellectual activity may be accompanied by a feeling of boredom and drowsiness, prone to rejecting too subjectively uninteresting activity, in response to increasing its complexity they are experiencing stress. First-year students cannot always properly and deeply assess their intellectual abilities, and have difficulty in overcoming obstacles during mental activity. They demonstrate productive performance of intellectual tasks, partially completing mental operations.
Low	First-year students distinguish subjects only by insignificant features, they distract from bright objects, have considerable difficulty in drawing logical conclusions when solving intelligent tasks, swindling to memorize and reproduce a small amount of information. They are in a state of exhaustion due to prolonged and intense influence of mental stress, quite often exhibit drowsiness and boredom, find a dominant motivation to complete intellectual work and rest, there are negative changes in mental and emotional states. Students perform mental activities based on the attitudes of others, evaluate their intellectual abilities, relying on their opinion and overcome difficulties in carrying out mental activities under their control. They do not complete mental actions and are only prone to reproduction while performing intellectual activity.

The majority of students (52.63%) showed a medium level of development of attention stability. They

demonstrated the ability to keep it on a certain object, not to distract and not weaken it, but only when they are motivated and depend on the peculiarities of these objects (their attractiveness, brightness, curiosity for the subject). 38.25% of first-year students are dominated by low levels of attention development. They are tending to be distracted by other bright objects and change the purposeful activity, also they have certain problems in performing long, monotonous and difficult mental activity.

9.12% of respondents are characterized by a high level of development of this attribute of attention, which indicates their ability to maintain a high intensity of attention for a long time, awareness of the importance of performing mental tasks, even in the presence of unfavorable working conditions, which is a basic background for intellectual productivity, and mental activity of students.

The results of the study by the method of "Investigating the analytic thinking" demonstrated that most first-year students (61.05%) were diagnosed with a medium or satisfactory level of thinking analytic development. This indicates that they have developed the ability to use logical conclusions in terms of attractiveness and importance of intellectual activity, which allows them to perform successfully various activities, including mental.

In 21.05% of the respondents revealed a high level of this indicator, which is identified in the effective solution of mental problems with the help of logical conclusions, due to high ability of planning their activities, finding specific solutions to problems and the desire to search. These first-year students while exercising mental activity are able to break down information into separate components, to implement a comprehensive analysis of these components, as well as to identify information as a whole, to identify several options for its solution, analyses and evaluate each option. They solve complex problems more efficiently and faster than others, make logical conclusions, even in the absence of information, look at the problem from different points of view, so they are able to find the best solution.

Unfortunately, in the course of the research, low results were also found on this characteristic of thinking. In particular, 16.14% showed low and 1.76% showed a very low level of analytical thinking. They have significant difficulties in drawing logical conclusions when solving intellectual problems, they have not developed the ability to theorize, find causal relationships between phenomena, have no skills to make reliable assumptions about the most likely options for the development of events, can't restore effectively the necessary information through logical conclusions which affects the process of mental activity and its effectiveness.

The technique "Study of the short-term memory amount", which is aimed at determining the amount of students' short-term memory, showed the following results (see Table 2). Most first-year students (69.12%) demonstrated a medium level of short-term memory, showing the ability to memorize and reproduce only relevant, interesting, necessary information and expressive features of individual subjects. Therefore, they have some potential for successful mental activity because the modern learning process is associated with a high mental load.

11.93% of respondents are characterized by a high level of this type of memory. They are able to memorize a large amount of intellectual information, retain and reproduce it promptly, which provides high mental performance. Despite this, 18.95% of students showed poor results on this indicator. Respondents, who have difficulty in perceiving information, memorizing and reproducing perceived material, being motivated to memorize only a small amount of it, require systematic training of memory.

Qualitative and quantitative analysis of the emotional component of mental performance, study especially the degree of manifestation of each of the states of performance (fatigue-monotony-satiety-stress) according to the method "Questionnaire DORS. Differentiated assessment of states of reduced performance (fatigue-monotony-supersaturation-stress)" determined that a moderate level of fatigue was found among 84.91% of students; they have such a state of performance only partially present in the process of their mental work, they have a slight decrease in endurance, the presence of some minor errors in the performance of intellectual activity, which almost does not affect its effectiveness.

At the same time, 11.58% of respondents showed a low level of this indicator. They do not feel exhausted, because the exhaustion in the performance of mental work is temporary and short-term in nature, performing it without significant mistakes, thus having considerable potential for processing mental tasks.

The study found that 3.51% of first-year students have a pronounced level of fatigue, they are in a state of exhaustion, performing mental exercises and developing tasks due to the prolonged and intense impact of mental stress, with a dominant motivation to complete intellectual work and rest. They observe a decline in labor productivity, a significant increase in mental activity errors, an increase in neuro-emotional excitability, and a decrease in overall endurance.

The moderate level of monotony that occurs in situations of monotonous work with frequent repetition of stereotypical actions and is accompanied by a feeling of boredom, drowsiness and dominant motivation to change activity prevails in 68.07% of the researches. 18.95% of students are characterized by low levels of this condition. They only sometimes have a slight decrease in activity with overall involvement, even in monotonous mental work. For 12.98% of first-year students there is a pronounced level of monotony, which is displayed in a decrease in attention and overall ability to willpower, and sometimes a refusal to perform mental activity.

It was found out that 71.93% of students were diagnosed with a moderate level of manifestation of this condition according to the index of *mental satiation*. They are sometimes inclined to reject too much subjectively uninteresting activity, to change a given stereotype of performing intelligent actions. 28.07% of respondents showed a low level of saturation. They are

able to perceive uninteresting mental activity without the desire to stop it.

The state of tension and stress (as one of the indicators of reduced working capacity) is partially available for most students (77.89% found a moderate level of manifestation of this condition). This suggests that they are partly tend to be stressed, which may be manifested in the overall mobilization of psychological and energy resources that is developed in response to increased complexity or subjective significance of the activity. Only 22.11% of first-year students were found to have low rates of stress. They do not have significant changes in their mental and emotional states, which ensures optimal mental performance.

According to the results of diagnosing the peculiarities of the *personality component* of mental capacity the questionnaire "Autonomy-dependence of personality in educational activities" found out that students with a high level of independence (75.09%), criticality (18.25%) and perseverance (23.16%) when performing their intellectual tasks demonstrate independence in defining the goals and objectives of mental activity, the ability to evaluate objectively and to implement obstinately. They have the habit and ability to analyze the reasons of success and failure at work, stand alone in defining their goals and objectives, and to choose the right ways to solve them. These traits are necessary for successful study in a higher education institution.

The study found out that students with a *medium* level of development of independence (22.11%), criticality (70.53%) and perseverance (69.47%) carry out new mental activity only with support, cannot always evaluate their intellectual abilities, have difficulties in overcoming obstacles in solving intellectual problems.

Respondents with a *low* level of independence (2.80%), criticality (11.23%) and perseverance (7.37%) perform mental activity with teacher's support, overcome difficulties in carrying out mental actions only under their control, evaluate own intellectual potential based on the opinion of others. That is why, they perform mental activity, focusing on the attitudes of others, assessing their intellectual capacity, relying on their opinion and overcoming difficulties in carrying out mental activities under their control.

Studying the *connective component* of the mental performance of the first-year students, we analyzed the indicators of their academic success according to the results of the winter exam.

In order to obtain the average indicators for a given component, the results of the whole sample, rather than of individual academic groups, were taken into account, in terms of absolute success, quality of knowledge and levels of intellectual activity performance. As a result of the empirical data processing, it is established that the student's absolute success rate is 92.93% of the total number of respondents. This is due to the fact that not all first-year students (namely 7.07%) received satisfactory grades during the session. They have training materials at the level of individual fragments, have difficulty completing their intellectual activity. The average quality of students' knowledge is 61.84%. This percentage of research is combined to make the session "excellent" and "excellent" and "good".

Analyzing the performance levels of intellectual activity (according to the results of the session), it was found that 4.95% of students showed high performance, showing special creative abilities in the exercise of intellectual activity, the ability to independently acquire knowledge, to complete the tasks, without the help of a teacher, to find and process the necessary information; the ability to use the acquired knowledge, to reveal their own slopes independently.

The analysis showed that 56.89% of first-year students demonstrated medium performance, concluding the session on the assessment of "excellent" and "good". They are not always fully capable to perform mental actions and show productive performance of intellectual tasks, and they possess freely the amount of educational material, correcting mistakes themselves, the number of which is small, able to generalize, systematize information under the guidance of the teacher.

According to the results of the winter examinations students with low level of performance (38.16%) were identified. This group of respondents, exercising the intellectual activity, is only prone to reproduce the educational material, expressing knowledge and understanding only of the basic provisions, with the help of a teacher they are able to analyze mental actions and correct mistakes, among which there are a considerable number of material ones.

The results of our theoretical and experimental achievements have allowed us to determine the levels of development (low, medium and high) and the qualitative indicators of mental performance, which were substantiated on the basis of the above criteria (Table 2).

Thus, assessing the peculiarities of students' mental performance during the period of adaptation to higher education, it was found out that the majority of students dominate the medium level of development of this ability by the identified components (average level of development of stability and selectivity of attention, analytical thinking, amount of short-term memory , monotony, satiety, stress, and average indicators of development of independence, criticality and perseverance in the exercise of mental activity).

The first-year students have the ability to distinguish subjects on both essential and insignificant grounds, have partially developed skills to generalize and schematize them, when being motivated they retain their attention on an interesting subject, use logical conclusions in terms of attractiveness of intellectual activity, more often they remember and refresh the items peculiarities.

The respondents were diagnosed with a slight decrease in endurance, errors in the performance of work. In situations of monotonous work with frequent repetition of stereotyped actions, they are prone to feel boredom, drowsiness with dominant motivation to change activity. Most students are sometimes inclined to reject too much subjectively uninteresting activity, which is manifested in a marked refusal of activity, or to make changes to a given stereotype of performance in a

situation of increased complexity or subjective significance of mental activity.

At the same time, first-year students are diagnosed with a medium level of development of such personality traits as: independence, criticality and perseverance in performing intellectual actions. In a situation where new mental activity is necessary, they are able to perform it with the support, they cannot always correctly and deeply assess their intellectual abilities and behavior, they seek better ways to perform successfully their mental work, they have difficulty in overcoming obstacles in their mental activity.

Most respondents showed a medium level of intellectual activity performance, having completed the session on the assessment of "excellent" and "good", by partially completing mental operations, demonstrating the productive performance of mental tasks, while having a sufficient amount of educational material, by correcting a small number of errors with the help of a teacher.

6 Conclusion

Thus, in general, first-year students have a medium level of development of mental capacity for all the selected components (cognitive, emotional, personal and connective), sufficient potential to successfully master the knowledge of high quality and productivity of mental work. In spite of this, quite low indicators of mental capacity for the identified components have been found out, which requires the development of a system of measures for improving the mental capacity of first year students.

In the process of screening, the scientists have identified the following advantages of using a computer complex of HC-psychotests:

1. The complex allowed to give multi-level and multiparametric characteristics of the mental states of the respondents using psychological, psychophysiological, physiological and social indicators.

2. The HC-psychotests realizes the possibility of registration and analysis of autonomic and emotional reactions during psychological and psychophysiological testing, which allows to evaluate the physiological cost of the activity, the level of adaptive capacity for loads with neuro-psychic stress (NPS), to predict more accurately the availability of NPS loads, with, in real working conditions.

3. Population standards by all methods are stored in the base of standards. With the help of the editor of the database of norms it is possible to view and edit them, taking into account data of own researches. It is possible to use multiple test bases for testing (for example, standard ones, supplied with the program, and your own) and a quick transition from one rule base to another.

4. The software of the complex allows to print paper test forms (incentive material and registration forms of testing) for the test-questionnaires, as well as to perform automated analysis using a scanner (editable) filled in by the test forms.

5. The program realizes the possibility of creating new testing methods according to the tasks of the study through a flexible system of settings of test parameters and with the help of the built-in editor of tests and templates of testing. The test editor allows you to specify instructions for completing the test tasks that appear on the monitor screen before testing, to create questionnaire texts and to establish principles for processing the data obtained. The template editor allows you to form a sequence of tests.

6. Initial test data such as physiological signal recordings, stimulus responses, selected response options, and more are available for viewing, processing and exporting to standard statistical processing programs to calculate specific results not provided by the mathematical apparatus of the program.

7. In the process of psycho-diagnostics of mental capacity, we conducted group testing (up to 10 people at a time) in an automated mode. This increased the capacity of the complex and simplified the task of examining a large group of people.

8. For each respondent registered in the database, upon receipt of results by any method, an individual norm database is formed. So, if an individual base is formed, the next test of this respondent program will "tell" whether the next result is typical for a person, regardless of population norms, which may differ from the individual ones.

Thanks to the use of the technology of HC-psychotests, computer psychodiagnostics techniques become the most attractive and widespread tools of psychologists conducting examinations in various fields and in the system of training of future specialists in higher education as well. Their development involves the creation of systems that construct a diagnostic conclusion based on the examination of a specific subject in the form of a coherent and consistent text, which quite fully reflects the psychological parameters measured by the test. In this case, the automated conclusion is individual for each respondent, and does not display some "average" characteristics and parameters that correspond to a certain contingent of people. Thus, computerization of psychodiagnostics techniques has a positive effect on improving the quality and reducing the cost of psychodiagnostics work in the process of psychological support for the professional development of a future specialist. The use of the HC-psychotests in the field of education helps to expand the professional horizons and iterate the practical and theoretical experience of the student; training of graduates to live in the information society; implementing a social order that focuses on global informatization processes.

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Formation of project competence of future environmentalists

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Abstract. We have gained successful experience in conducting educational projects with students-environmentalists of various thematic areas. The topics of ecological projects was related to a practical, professionally oriented block of the curriculum and are intended to deepen the knowledge of individual students in a certain area in order to differentiate the learning process. Most often, project topics relate to a specific practical issue that is relevant to real life. At the same time, it requires the acquisition of students' knowledge from different subjects stimulates systematic creative thinking, turning up the research skills and opens opportunities for effective using of ICT in the project activity.

Introduction

Education is a priority tool for the sustainable progress of society, because the level of socio-economical amplification of society, in general, or of the state, is determined by the level of education and culture of its citizens. "Providing inclusive and equitable quality education and promoting learning opportunities during life for all" is one of the main indicators of a sustainable society progress [1]. The role of education for sustainable development is a major and urgent problem of scientific research, the vast majority of which is focused on the environmental component of education, for example, V. M. Bogolyubov [2], M. Klimenko [3], Y. Skyba [4]. In our opinion, higher ecological education is the most important factor in formation thinking focused on a sustainable harmonious future. The task of modern higher ecological education is preparing of environmentalists, who able to use their knowledge in a professional manner, taking into account the goals and objectives of sustainable development.

Providing quality training for future environmentalists is impossible without the organization of an educational process focused on the formation of professional competencies, which requires knowledge of the theoretical bases, tools and methods of solving professional problems; ability to analyze, predict their activity and independently choose the means and ways of action in certain situations; ability to self-development and self-realization of mastering modern scientific achievements and their implementation. It is forcing to find new ways of preparing future environmentalists in the conditions of rapid development of technologies and communications by using the method of projects – pedagogical technology, which includes a set of research, search, and problematic methods, creative in its essence. Therefore, when we talk about the project method, we are referring to the method of achieving the didactic goal through detailed elaboration of the problem (technology), which must be complete with a real, tangible practical result, designed in a certain way. The project method is based on the idea that constitutes the essence of the concept of "project", its focus on the result, which is obtained when solving a practically or theoretically significant problem.

"According to recent research, project work meets, to some degree, the expectations of its proponents in that the method improves – besides factual learning – the students' motivation, self-confidence, and critical thinking as well as their problem solving, decision making, investigative, collaborative skills. But there is evidence, too, that there exist barriers hindering the achievement of the objectives intended and striven for since neither students nor teachers always fulfill the necessary premises and qualifications completely. Teachers, for example, have difficulties to suggest and design challenging projects, monitor progress, give feedback and support when and where is needed, to create and maintain an atmosphere of study and work, and lastly develop tools for assessing the results. Correspondingly, students often feel ill prepared and overwhelmed by the complexity of the tasks at hand, i.e. they have not a clue how to define the problem, choose the proper methodology, find the necessary resources, revise plans and procedures if appropriate, keep deadlines and present the results fittingly. After all, projects can fail since few students are constantly

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disposed to self-directed, creative, innovative learning. In principle, they enjoy the freedom of action the project method offers them but, as in traditional settings, they frequently employ strategies of bargaining, shirking, and playing dumb in order to lessen, avoid or even resist the additional time, energy, and imagination required by project work." [5]. The method of projects always involves the solution of a problem, and the solution of the problem involves, on the one hand, the use of a variety of different methods and learning tools, and on the other hand – the need to integrate knowledge and skills from different science, technology, creativity. The results of completed projects should be reality and ready for implementation. So far, the method of projects has not been used in the preparation of environmentalists, cause previous studies are devoted to raising the level of ecological consciousness, culture and outlook; improvement of existing technologies of higher environmental education; formation of professional competence of environmentalists.

"The project method has several steps: the teacher and the students examine a certain environmental topic, they choose a problem which is important to them, and then they develop and carry out an action plan. With each step the students assume more and more the role of a manager able to treat environmental topics. Responsibility is passed on gradually from the teacher to the students; at the beginning it is the teacher who guides the process and establishes the main lines, later the students take over the project management, and the teacher becomes an observer. The teacher controls the advancement of the students, he ensures the possibility to change roles by developing the knowledge and skills of the students, assessing their performance with criticism, and introducing new ideas and methods in the learning process, thus eliminating the factors which limit their development" [6].

Thus, it is possible to formulate such hypothesis of research: the method of projects provides the higher level of formation of professional competences of future environmentalists, which in turn will increase their ability to work in the conditions of sustainable progress of society. In addition, the use of computer technology in the project training of future environmentalists will promote progress of their communication skills and processing results.

Methods

Research using project method by future environmentalists were used some methods: analysis, synthesis, modeling; pedagogical experiment; statistical analysis.

For the purpose of evaluation of future environmentalists, the criteria for the evaluation (Table 1) of their professional competences were determined [7], which conventionally called "project": K04. Ability to develop and manage projects; K17. Ability to independently develop environmental projects by creatively applying existing and generating new ideas and relevant programmatic learning outcomes; PR04. Know the legal and ethical standards for the assessment of professional activity, development and implementation of socially significant environmental projects in the conflicting requirements; PR05. Demonstrate the ability to organize collective activities and implement complex environmental projects, taking into account available resources and time constraints.

Table 1. Criteria formation of project competence.

The level of competence	**High**	**Enough**	**Medium**	**Base**
ECTS credits	90-100	74-89	60-73	35-59
Formation criterion	Ability to solve research and creative tasks by applying the project method	Ability to justify approaches to the implementation of different stages of the project	Ability to perform typical tasks under the guidance of a teacher / student	Have of basic skills, inability to organize and work as a team on a project

Material

The result of the implementation of project training is the development and protection of a portfolio of educational or scientific project, which involves the use of information and communication technologies and compliance with specific requirements for content and structure.

"Portfolio of project is a set of informational, didactic and methodological materials to the educational project, designed with the purpose of its effective organization and training of the subject" [8, p. 134].

We propose to determine the topic of students' research projects according to the topic of their qualification (course) work. This avoids the automaticity in the creation of individual elements of the e-portfolio, because students are interested in their portfolio not only respond the formal requirements, but also reveals the content of their qualification (course) work. They find a lot of useful information not only for their project portfolio, but also for their qualification work, they learn how to conduct research and to process its results, to build different types of graphs and diagrams. Creating a publication, presentation, blog and website allows you to diversify their qualification (course) work. It is especially useful to create a presentation on the topic of the project: students can use it both in defense of the project and in the defense of qualification (course) work.

An environmental project is a program or plan of consistent actions that is likely to improve the environmental state of an existing locality. In the context of the sustainable development concept, scale of project implementation may vary dynamically, depending on the number of participants and their place of residence. We trusted it as a protest from the pupil Greta Thunberg, who is struggling with global warming and becoming one of the most influential teens in 2018 for the TIME edition [9] are widely known around the world. In

August 2018, Greta made her famous by launching the first school strike for climate under the Swedish Parliament building. She came under the building every Friday, demanding that legislators support the Paris Climate Agreement. The main objective of the Paris Agreement is to prevent the global average temperature rise within 2°C (preferably not more than 1,5°C) in relation to pre-industrial period. The second goal of the agreement is to reduce greenhouse gas emissions to zero during the second half of the 21st century. In the conditions of realization of the concept of sustainable development of mankind, 21 main indicators of which change, track the results of each country have been identified (Fig. 1).

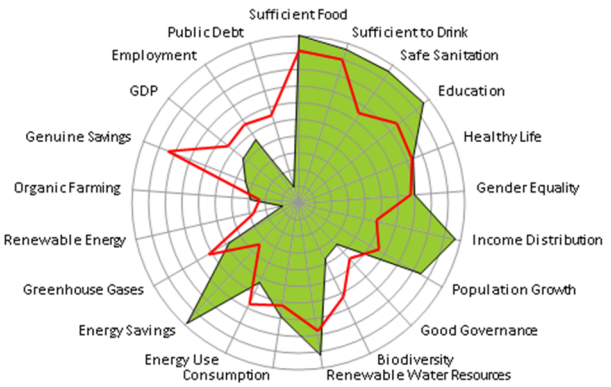

Fig. 1. The spiderweb shows the score of each of the 21 indicators of the Ukraine, on a scale of 1-10 (10=sustainable, 1=not sustainable). The line is the weighted average score of all countries (http://www.ssfindex.com/).

The use of this web resource (http://www.ssfindex.com/) makes it possible to track the dynamics of change for each country indicator (fig. 2) and to determine whether the government and the population of the country are taking action to implement the concept of sustainable development.

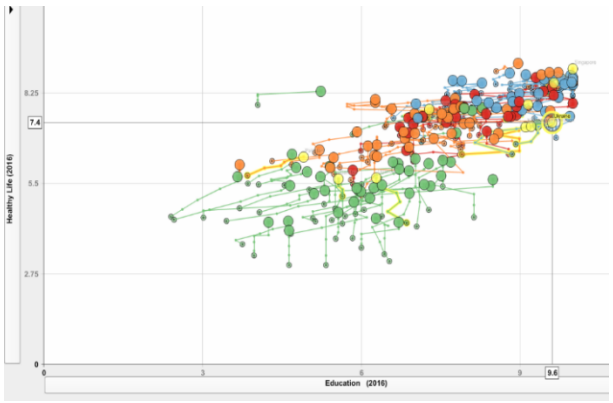

Fig. 2 Dynamics of change of selected indicators (Education and Healthy Life).

Also with the interactive map of the world (Fig. 3) students can track the same indicators simultaneously for all countries of the world.

However, it will be much more valuable not to look at these indicators, but also to perform an active benchmarking of data for different countries, for example, using the Excel spreadsheet (Fig. 4), which contains these indicators from 2006 to 2016.

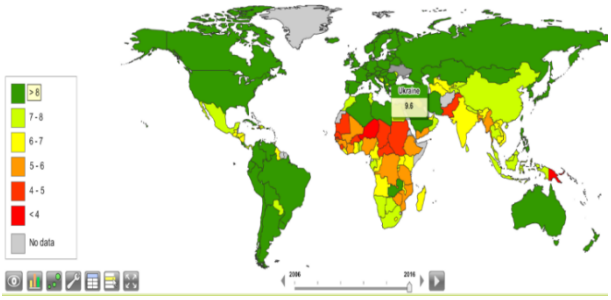

Fig. 3. Interactive map of the world indicators of sustainable development.

	A	K	L	M	N	O	P	Q
1	2016	Environmental Wellbeing						
2		Natural Resources			Climate &Energy			
3		Biodiversity	Renewable Water Resources	Consumption	Energy Use	Energy Savings	Greenhouse Gases	Renewable Energy
4		Indicators						
146	Turkmenistan	3,4	1,0	5,5	1,0	2,0	1,0	1,0
147	Uganda	7,5	9,8	6,1	9,3	5,4	9,8	8,3
148	Ukraine	3,7	9,2	6,9	5,3	9,8	4,8	1,0
149	United Arab Emirates	5,5	1,0	3,8	1,0	3,8	1,0	1,0

Fig. 4. Excel spreadsheet, which contains indicators of sustainable development from 2006 to 2016.

It will also be valuable for future environmentalists to analyze the dynamics of changing each indicator for the selected country and identify the cause of its rise or fall.

After that, we propose to future environmentalists to analyze the table 2 and choose the topic of environmental projects in two directions:

1) to maintain the level of the achieved indicator and its dynamics until growth;

2) to increase of the selected indicator.

For example, for the Renewable Water Resources indicator we observe a negative trend (a decrease of 0.1), and despite the sufficiently high value of the indicator (9.2 out of 10), we should pay attention to it, because the world's water resources are suitable for consumption, have decreased significantly over the last 20 years.

According to this indicator, we offer students a number of indicative topics of environmental projects:

- "Save the small river – save the ocean";
- "Clean River – Healthy Man";
- "Monitoring domestic water consumption";
- "Responsibility time: how do I pollute the water?"
- "We do not know the price of water until the well runs dry";
- "River death – a tragedy of the region";
- "Helping Waterfowl";
- "In the lens – the reservoir";

• "ECO-style living: a phosphate-free household";
• "We reduce the amount of household waste into water";
• "Collection of mechanical waste in reservoirs without harm to their inhabitants";
• "Collecting greasy stains from reservoirs after shipwrecks";
• "Environmental problems of using household chemicals".

Table 2. Indicators of sustainable development (Environmental Wellbeing) from 2006 to 2016 for Ukraine

Ukraine	Environmental Wellbeing						
	Natural Resources			Climate & Energy			
	Biodiversity	Renewable Water Resources	Consumption	Energy Use	Energy Savings	Greenhouse Gases	Renewable Energy
2006	3,7	9,3	5,8	3,9	2,2	3,8	1,0
2008	3,7	9,1	6,0	4,1	3,9	3,6	1,0
2010	3,7	9,1	4,9	4,2	6,0	3,6	1,0
2012	3,7	9,2	6,1	4,2	5,4	4,2	1,0
2014	3,7	9,2	5,2	4,6	6,9	4,0	1,0
2016	3,7	9,2	6,9	5,3	9,8	4,8	1,0
Progress Scores 2006-2016	0,0	-0,1	1,1	1,4	7,7	1,0	0,0

Stages of implementation of environmental project:
- **team formation** (usually students of specialties "Ecology");
- **selection and formulation of the project theme** (for example, the specified project theme might look like: "Environmental problems of using household chemicals (for example, dishwashing detergents)");
- **determination of the relation to the problem**: what significance this project will have for the project participants, for other people; what benefit will society bring to the implementation of the project;
- **planning for a project** begins with a collective discussion. This is, first and foremost, an exchange of views and a reconciliation of students' interests; developing primary ideas based on existing knowledge and discussing controversial issues. Tutor, project manager should focus students' attention on the overall theme of the project, on subtopics, on their relationship, the course and timing of work on the project; encourage them to research independently; to group and summarize with the project implementing students ideas in the most clear and comprehensible form for them, to determine the direction of the research work and to help the students to formulate 5-6 related subtopics within the research topic and to determine the timing of individual tasks; start a project implementation journal.
- **examination the problem**: find the right information, meet with experts, make a list of necessary materials, equipment and more. This is a stage of independent research, acquisition and analysis of information, during which each student: refines and formulates his own task, based on the purpose of the whole project as and the task of his group in particular; searches and collects information, analyzes and interprets the data obtained.
- **identifying ways to solve the impact of the dishwasher on water**. At this stage, the obtained information was systematized, so the tutor should help groups or individual students summarize the obtained results for each of the tasks and determine the ways in which they can be accomplished.
- **planning of practical activities**: analysis of the chemical composition of popular dishwashing detergents, research of the ability to dissolve the individual constituents of detergents in water and their impact on living organisms, selection of means to neutralize the negative impact of constituent detergents on living organisms;
- **implementation of practical actions aimed at "health improvement" of nature**: analysis of the results of experimental studies and search for the least harmful detergent;
- **discussion of the results of the work:** group discussion, round table, consultations with the project manager (tutor), consultations with experts. At this stage, students reflect on the data and ways to achieve the result; discuss and prepare the final presentation of project results. The students not only present the results and conclusions, but also describe the techniques by which information was obtained and analyzed; tell about the problems that they had to face when working on the project. In order to successfully organize the presentation of the finished project, the tutor - project manager , along with the students, think through of: how best to apply each project participant's individual intellectual and communicative abilities,; time for preparation and presentation; presentation scenario; project presentation form; prospects for further work on this project.
- **presentation of the work should include:** a description of the project, including the object, subject, purpose, tasks, materials, actions, results; suggestions or ideas; illustrations or computer graphics; interpretation (of specific facts, events, processes, etc.); evaluation and analysis: charts or graphs; justification (conclusions, suggestions, recommendations, etc.);
- **planning of further ecological work:** analysis of the impact of project results on the selected indicator and deciding on the continuation of projects within this indicator by popularizing the project, spreading it to more consumers.

For creating all these elements we use of G Suite package, which has all the necessary cloud services not only for the development of collective projects, but also for the work in the mode of shared access. It is enables the teachers (project managers) to monitor the progress of the project, because cloud computing is a data processing technology in which software is provided to the user as an Internet service. The user has access to their own data, but cannot manage and have not to take care of the infrastructure, only operating system (OS) and software with which it operates. Cloud computing is a paradigm in which information is constantly stored on servers on the Internet and temporarily cached on the client side, such as personal computers, game consoles, laptops, smartphones, etc. [10].

There are three main areas of implementation of "cloud computing" [11]:
- SaaS, Software as a Service. Almost any application that works through the World Wide Web.
- PaaS, Platform as a Service. It allows you to create and implement hosting-based applications using the programming language and packages from the provider. These include G Suite from Google.
- IaaS, Infrastructure as a Service). This includes the use of server and disk space away from the user, which is also typical of Google Drive.

Cloud computing includes the concept of Web 3.0 and other technological trends that are common to the belief that the Internet is able to satisfy user needs for data processing. For example, G Suite provides software online (without installation), accessed through an Internet browser while the software and data are stored on Google's servers.

The project activity in cloud environment has characteristics such as [12]: interdisciplinarity (integrated learning), collaboration (active communication and teamwork), availability of results (application of scientific and technical knowledge in real life), preparation students for technological innovation of life.

The basics of the project method was showed on the example of technical disciplines [13].

Results

Considering that, the teaching of technological and informational disciplines for future environmentalists is in interaction with other factors (scientific measures, industrial practice or internship at the enterprise, cooperation with potential employers) and is a multifactorial, trial implementation of the developed methodology in the education. Competency Standards of future environmentalists demanded carrying out of pedagogical experiment, which provides detection of its efficiency.

Whereas the pedagogical experiment in our study was aimed at establishing the effectiveness of the formation project competence of future environmentalists, it was a comparative experiment. For its conducting two groups were formed – experimental and control. The experiment was organized in such a way that the results of implementation of the project method in the teaching of future environmentalists for experimental groups were compared with the results of students from control groups (where teaching was carried out according to the traditional method) using the same methods diagnostics.

The experimental and control group implement different variants of experimental work, with all the conditions of the educational process in these groups were the same except for the condition that was dependence by the establishment of methodological innovations and was subject to testing. The sampling amount formed taking into account the number of students of the specialty "Ecology".

The 410 students participated in the molding experiment. The 203 were assigned to the experimental group, 207 were assigned to the control group (this division was made taking into account the distribution of students in academic groups).

The differences between the experimental and control samplings (Fig. 5) were determined using the Fisher criterion φ^*. The test of the statistical hypothesis against the coincidence of the differences in the results was made at the level of significance $\alpha = 0{,}05$.

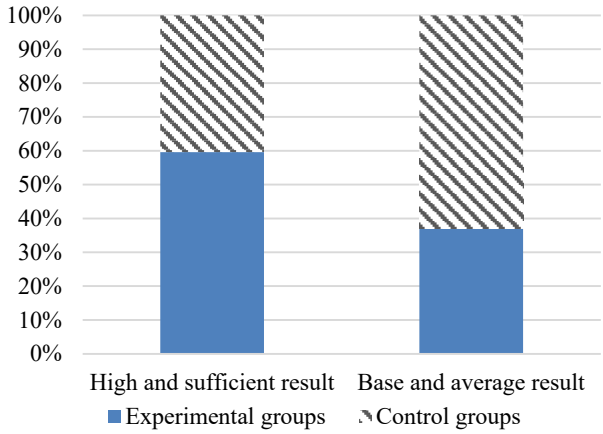

Fig. 5. The proportion of students (in %) who have an appropriate level of project competence.

We construct a table 3 of output data of the level of learning achievement of two samplings: control and experimental groups to determine the Fisher criterion.

Table 3. The results of the formation stage of the pedagogical experiment.

Sampling	High and sufficient result			Base and average result			Sum	φ^*
	Number of students.	%	The value of φ (in radians)	Number of students.	%	The value of φ (in radians)		
Experimental groups	139	68,5%	1,95	64	31,5%	1,19	203	5,01
Control groups	96	46,4%	1,50	111	53,6%	1,64	207	1,04

The critical value of φ^* for the level of statistical significance $\alpha = 0{,}05$ is $\varphi^*_{cr} = 1{,}64$). It turned out that the value of φ^* exceeds the critical value, which confirms the effectiveness of the auto-methodology to increase the level of project competence of future environmentalists.

Thus, the level of project competence of future environmentalists who were part of the experimental group increased significantly. This means that, the using of the project method directly affects the quality of professional training and leads to statistically significant positive dynamics of the level of professional competence of students.

It was proved, that created method of formation the project competence of future environmentalists is more

effective than traditional. The results of students' activity in realization of their projects based on the study of the impact of industrial and urbanistic forms of human activity testify to the effectiveness of the developing of the project competence of future environmentalists.

Thus, the hypothesis of the study was confirmed that the project method provides a higher level of professional competences of future environmentalists, which in turn will increase their ability to work in the conditions of sustainable development of society, and the use of computer technologies in the project training of future environmentalists contributed to the development of their skills communication and speed of processing results.

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The use of information and communication technologies in training ecology students

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Abstract. Increasing demand for experts capable of high-quality assessment of the impact of a particular planned activity on the environment involves a more effective use of information and communication technologies (ICT) in the educational process of training ecology students. The authors present a methodology for students to study the educational material of the "Environmental Impact Assessment" course by using ICT. The methodology and algorithm for using the Padlet interactive whiteboard, Mindomo mind maps, Easel infographics, Google Drive and Google Docs in lectures and practical lessons are described. Particular attention is paid to the preparation of a group project using ICT. Tested in the Ternopil Volodymyr Hnatiuk National Pedagogical University, the methodology allows to implement a number of tasks such as: promotion of intensification and effectiveness of teaching; acquisition of practical skills to quickly find the necessary information on various online resources for ecology students; simulation of the real procedure of environmental impact assessment in the classroom; development of the ability to professionally communicate with experts in other fields of knowledge or activity, etc. Examination of the results of using ICT to study the "Environmental Impact Assessment" course has shown a significant increase in informational literacy among ecology students and their individual professional growth.

1 Problem statement

Long-term use of biosphere resources by humans has led to a significant transformation of the natural environment. The analysis of degradation processes indicates a violation of regulatory mechanisms that support the stability and durability of ecosystems. Awareness of the problem of natural ecosystems losing their ability of self-recovery has prompted the search for ways to stabilize their state. However, in modern environmental strategies and approaches considerable attention is paid not only to technologies to overcome the already existing effects of anthropogenic impact but also to the development of preventive measures that should avert the negative impact of economic activity on the environment.

Such measures include environmental impact assessment, the purpose of which is to carry out a predictive environmental impact assessment of a particular industrial object or activity at its development stage. According to the expert findings provided in the environmental impact assessment, it is possible to identify environmentally damaging economic projects in advance. Alongside with environmental protection technologies that can reduce anthropogenic pressure, preventive measures ensure the implementation of a sustainable development strategy in the field of ecology. Environmental impact assessment is one of such preventative measures.

Therefore, the compulsory "Environmental Impact Assessment" (EIA) course is included in the curriculum for bachelors of the 101 "Ecology" speciality of Ternopil Volodymyr Hnatiuk National Pedagogical University (TNPU). Studying this subject provides students with the necessary professional skills to qualify as an ecology expert. It should be noted that the learning outcomes provided by the Higher Education Standard of the 101 "Ecology" speciality for the first (bachelor) degree of higher education (according to the decree of the Ministry of Education No 1076 of 04.10.2018), apart from the cumulative knowledge, skills and proficiencies, students must also acquire the following general competencies:

- ✓ proficiency in using information and communication technologies;
- ✓ ability to adapt and act in new situations;
- ✓ ability to communicate with professionals of different spheres and of various levels (with experts in other fields of knowledge/types of economic activity);
- ✓ ability to work in a team;
- ✓ proficiency in interpersonal interaction.

An ecology student can become a competitive expert in ecology and be able to respond to the needs of society only when they master professional competencies, which are also specified in the standard, namely:

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1. The knowledge of current national and international ecological legislation achievements;
2. The ability to evaluate the impact of technogenesis on the state of the environment and identify ecological risks associated with production activities;
3. The ability to use modern information resources for ecological research;
4. The ability to inform the public about the state of ecological security and the sustainable management of nature.

In general, such a range of competencies as a learning outcome reflects not only the extraordinary dynamism of modern ecology development and its research methods but also the approaches to obtain reliable up-to-date information for a prompt and substantiated response to environmental changes. On the other hand, the content component of the standard for training ecologists stipulates that within the legally set periods of training they must not only accurately master the knowledge base of the profession, but also new methods and technologies of obtaining relevant information to identify trends in the state of ecological objects under the influence of anthropogenic activity.

Environmental impact assessment in Ukraine began to be carried out in December 2017, which is why the "Environmental Impact Assessment" course appeared in the bachelor's degree program in the 101 "Ecology" speciality of TNPU only in 2018. This fact determines the relevance of the development of its educational and methodological base.

Our distinct understanding of these tasks within this course of study has led to the search for methods and learning tools through which the educational process would ensure a great didactic effect. Being concerned about the professional image of our students we perceived this problem as a task that needed an immediate and high-quality solution. In our opinion, one of the ways to solve this problem is to use information and communication technologies while studying the "Environmental Impact Assessment" course.

2 Literature review

The strategy for sustainable development in the field of ecology involves scientific studies concerning the reduction of anthropogenic impact on the environment. Recently (since 2018), the topic of ecological studies in Ukraine has included the issue of environmental impact assessment. The analysis of the degree of scientific knowledge reveals a lack of study of this issue in contemporary scientific literature.

A. J. Macrinnon et al. study the history of use of science in environmental impact assessment, as well as provide a conceptual and technical overview of scientific developments related to environmental impact assessment since its inception in the early 1970s [1].

In Ukraine, since the advent of environmental impact assessment scientists in the field of ecology I. Barna and O. Naumenko have conducted an analysis of environmental impact assessment in comparison with ecological examination [2, 3].

The issues of using ICT to achieve sustainable development goals have been raised in the works of E. Williams [4]. J. Houghton explores how the Internet and ICT can help solve environmental problems in developing countries [5].

ICT has a major impact on education as it opens up opportunities to introduce completely new teaching methods. The introduction of ICT in the educational process is substantiated in the works of many domestic and foreign scholars [6-10]. V. V. Fedoniuk, V. V. Ivantsiv, M. A. Fedoniuk, S. G. Pankevych provide examples of use of internet resources in the practical course of the "Natural Reserves Education" subject [11]. The results show that ICT qualitatively influence the improvement of teaching and evaluation methods and contribute to the development of students' information culture [12, 13].

However, researchers have not outlined ways to use ICT in the process of studying the "Environmental Impact Assessment" course so that ecology students could acquire practical skills. Without this approach it is difficult to provide quality professional training of future experts.

Thus, the research analysis allows us to infer that there is a lack of scientific papers that would depict the features of the use of ICT in the study of the "Environmental Impact Assessment" course, which makes the above issues insufficiently explored.

The article is aimed at explaining the features of utilization of information and communication technologies in the process of studying an academic discipline by future ecology experts.

The object of study involves an analysis of application of information and communication technologies in different types of lessons in higher education institutions when studying the "Environmental Impact Assessment" course.

3 Results and discussion

At present sustainable development of Ukraine is impossible without EIA. Environmental impact assessment is a procedure in which potential investors, who plan a specific type of activity, interact with state inspectors, who are required to provide an environmental impact assessment report. The participants also include experts who at the request of potential investors must evaluate the impact of the planned activity on the environment and, if necessary, to propose measures to bring the environmental impact of such an activity to the current regulations of the environmental legislation. The EIA procedure calls forth the involvement of the public, which is empowered to approve or reject the planned activity projects based on the consequences for the environment. Thus, EIA involves the work of investors, ecologists, state experts and the public with basic environmental impact assessment documents, the features of preparation of which future ecologists need to know.

EIA in Ukraine has been carried out since December 18, 2017, according to the law of Ukraine on environmental impact assessment. In December 2019,

two years passed since EIA was first used, however, the applied aspects of its implementation require methodological development and improvement. There is also a lack of textbooks for professional training of EIA experts. This significantly complicates the teaching process of this course. For these reasons, the search for effective teaching methods of this subject is relevant and substantiated. It should be taken into consideration that while teaching the "Environmental Impact Assessment" course it is necessary to develop the students' ability to work both as ecology experts and as state experts. Ecology experts need to be able to prepare EIA reports. State experts need to be able to analyze the EIA reports to issue the appropriate conclusion. These two roles are different, but studying the "Environmental Impact Assessment" course stipulates that the educational competencies of both components of the future profession are developed.

We believe that comparative method with the aid of ICT is the most optimal in this situation. The latter is a necessary component of the EIA educational process for several reasons: changes to laws and subordinate legislations are most promptly reflected on official websites of the relevant ministry, institutions and organizations; the EIA procedure involves the registration of a potential investor in an e-cabinet, online filing of documents in the EIA register, online communication with the public and state institutions. This involves the formation of future ecology experts' information competence. All of this has been taken into account by us when developing a methodology for using ICT in the process of teaching the "Environmental Impact Assessment" course.

At the initial stage, we examined information and communication technologies, and as a result, found online resources that allow professors to create conditions in the academic setting for the students' active educational trajectory (Fig. 1).

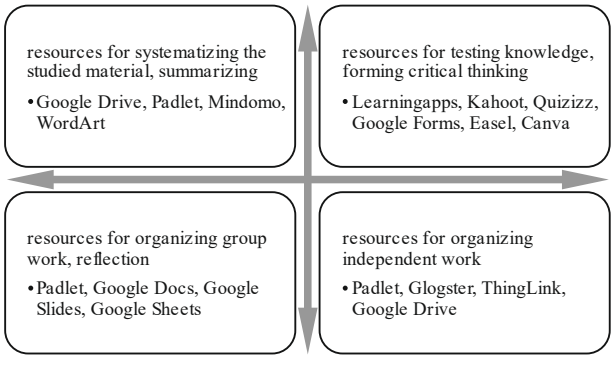

Fig. 1. ICT in the academic setting.

At the second stage, the most effective online resources for different forms of the educational process (lectures, practical training, group projects) were selected. At the third stage, the developed methodology was tested during the "Environmental Impact Assessment" course.

Lectures. The use of ICT for this form of educational process compensates for the lack of textbooks and manuals for this course. The use of ICT allows students to create an electronic synopsis using internet resources and the Padlet interactive whiteboard, which provides the opportunity to discuss a higher number of questions than that of a traditional lecture.

The lessons were held in computer classrooms where each student was able to use ICT. Issues like course objectives and methods of conducting the lessons, ways of evaluating the level of professional and informational competence, and determined methods of preparing projects using ICT were discussed in the first lecture.

Among the wide variety of online services for conducting lectures interactive whiteboards have been selected to create teaching materials that contain certain information in the form of text, pictures, graphs, photos, videos, infographics, namely:

- ✓ Padlet;
- ✓ Whiteboard;
- ✓ Realtime Board;
- ✓ WikiWall;
- ✓ Dabbleboard;
- ✓ Popplet.

The use of these boards not only allows professors to communicate in real-time online but also to record the lesson [14]. Recording the lesson can be done both by the professor and the students. In addition, professors and students can leave text notes and comments on certain elements, upload and edit files, attach text and pdf files, graphic images using special services on the virtual board. Using simple and straightforward tools, professors can clearly visualize information as a diagram. It is important that group work is integrated on a single site.

In the educational process, virtual boards can be created to:

- ✓ post information on the studied topic;
- ✓ post information or questions to find information;
- ✓ brainstorm to gather ideas;
- ✓ organize group work to find a collective opinion concerning the problem;
- ✓ do projects together.

Such virtual board learning opportunities have allowed them to be used in the "Environmental Impact Assessment" course lectures. The use of the Padlet interactive whiteboard turned out to be the most optimal use of a virtual board. One of the advantages of this service is that Padlet is convenient to use as a document storage system. Materials uploaded to the board will be available at any time, which is especially relevant for students who were absent from the lesson and those in distance learning.

As an example, we demonstrate the methodology of conducting a lecture on the topic: "EIA as a mechanism to ensure ecological safety".

The first post on the board contained information about the subject of the lesson and the task. It was convenient to search for the EIA law from a dropdown menu of the post directly on the board, which allows you to optimize time spent (without opening new browser tabs) (Fig. 2). The search result leads to an image with a link to the law on environmental impact assessment, as the main document for studying (Fig. 3).

The law of Ukraine on environmental impact assessment (lecture), **topic:** "EIA as a mechanism of ensuring environmental security", **task:** learn about the

article 1 of the law of Ukraine on environmental impact assessment. In the lecture, after reading another article of the law the students were asked questions in the following sequence:

Question 1. What terms and concepts are confusing or unknown?

Question 2. Define the main content of the article of law, for instance, article 1.

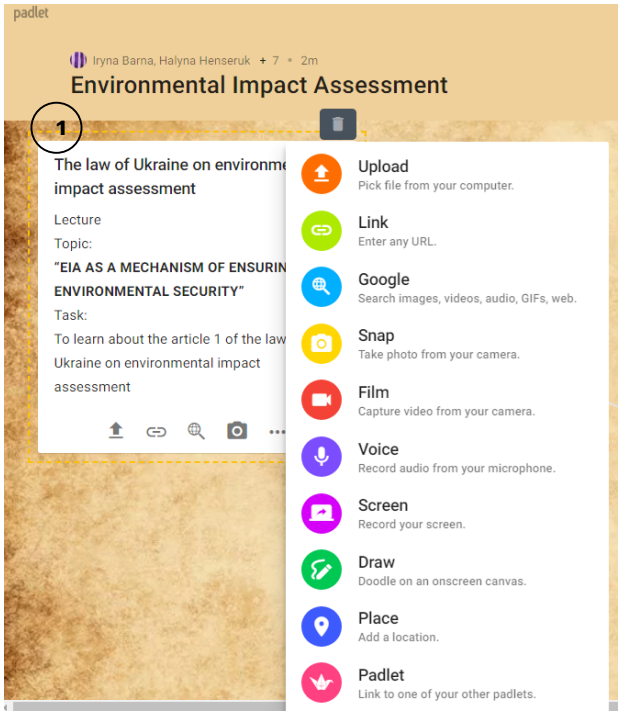

Fig. 2. Padlet board content 1 (information search).

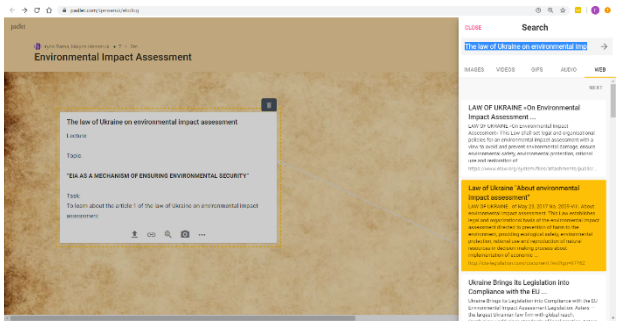

Fig. 3. Padlet board content 2 (information search).

Typically, in response to the **first question,** students could have written: "What is an institutional framework?". The most confusing terms were determined by allowing students to mutually evaluate their posts. Using Padlet's search engine, students found definitions of these terms, offered links, established connections to posts with the corresponding caption on the connection line. In this way, the process of learning new material in the short term "materialized" on the Padlet board during group work (Fig. 4).

It should be noted that at the initial stages of studying the course the students were not active. This is partly due to the inability to use such information and communication technologies. However, within 10-15 minutes students quickly gained proficiency in the means of ICT, became active and showed considerable interest. At this stage, the lesson was conducted in the form of a brainstorming session. This teaching format contributed to the formation of a positive emotional dimension to the lessons, which increased didactic results.

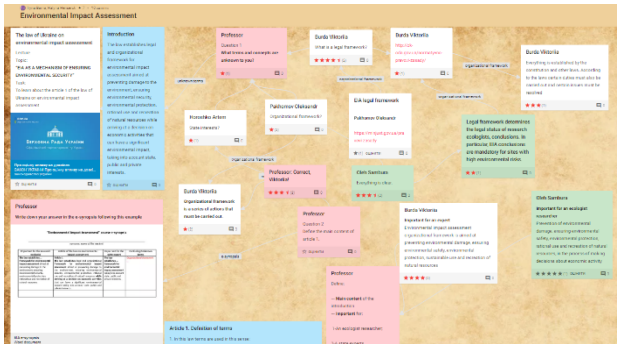

Fig. 4. Padlet board content (information discussion).

Being able to access a significant portion of articles of the EIA law in Padlet's search engine via hyperlinks was a great advantage. For instance, article 1: "Planned activity is planned economic activity that includes construction, reconstruction, ... according to the **criteria** (originally a hyperlink), approved by the Cabinet of Ministers of Ukraine".

While working with the Padlet board students created a document as a part of an e-synopsis and saved it on a virtual drive. Students took notes (as a separate document) in the form of a table which had 4 columns. While filling in each of the columns the students:

1. studied an article of the law;
2. established the main content of the article of the law;
3. established the significance of the article for an ecology expert;
4. established the significance of the article for a state expert.

To answer the **second question** students analyzed the content highlighting the main content (in bold or with a colour) (Fig. 5).

E-synopsis «Environmental Impact Assessment» course

surname, name of the student

Important for the ecologist-researcher	Article of the law on environmental impact assessment	Important for the state expert	Confusing/unknown terms
The law establishes ... framework for environmental impact assessment aimed at preventing damage to the environment, ensuring environmental security, environmental protection, rational use and recreation of natural resources	**The law establishes** legal and institutional **framework for environmental impact assessment** aimed at preventing damage to the environment, ensuring environmental security, environmental protection, rational use and recreation of natural resources **while arriving at a decision on economic activities** that can have a significant environmental impact, taking into account state, public and private interests.	**The law establishes ... framework for environmental impact assessment** taking into account state, public and private interests.	Institutional framework-...

Fig. 5. Content of the e-synopsis.

The format of the table in the text document of the e-synopsis made it easy to organize and summarize the learning material and promoted the qualitative acquisition of knowledge and formation of professional skills. The e-synopsis thus fulfilled the function of a textbook to study the course, prepare for practical lessons and the basis for proper and timely completion of a group project. To involve all students in active participation the professor provided them with the chance to analyze all the terms using ICT and to take notes for themselves.

The professor's comments on the students' posts on the Padlet board made it possible for the students to focus on the key information and transfer it to their e-synopsis. In the case of repeated references to the article in the law, the students did not have to reopen the document since the information had already been saved in their e-synopsis (Fig. 6, Fig. 7).

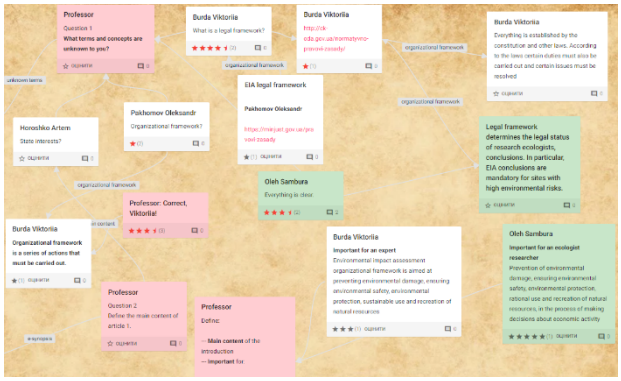

Fig. 6. Professor's comments on the students' posts.

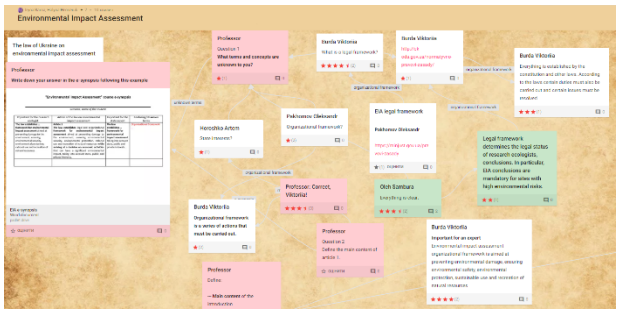

Fig. 7. Students' posts assessment.

The students analyzed the connections between the articles of the law in an electronic document for a fully understand them and to apply them properly.

Group project. The educational process of the "Environmental Impact Assessment" course included preparation of an e-project with mind maps by two groups of students. Today the mind map technology is a new tool for structuring and storing information in human memory. One effective way of structuring memorization stages is to provide educational material with a tree structure. Such structures are widely used everywhere where it is necessary to picture a large amount of information in a short and compact way. Mind maps are a convenient and effective technique for visualizing thought and graphic displays of associative connections. They can be used to create and capture new ideas, analyze and systematize information, and make decisions.

There are many online services to create connection diagrams in mind maps [15]. The most popular ones are Mindomo, MAPMYself, Mind42, MindMap, Glinkr. To create an EIA project, we suggest using Mindomo. Designing a mind map allowed the students to create a system of related data and identify the stages of activity the sequence of which is consistent with the logic of the EIA process, which in our case will allow us to construct an algorithm of actions of an ecology researcher or an ecology expert (Fig. 8).

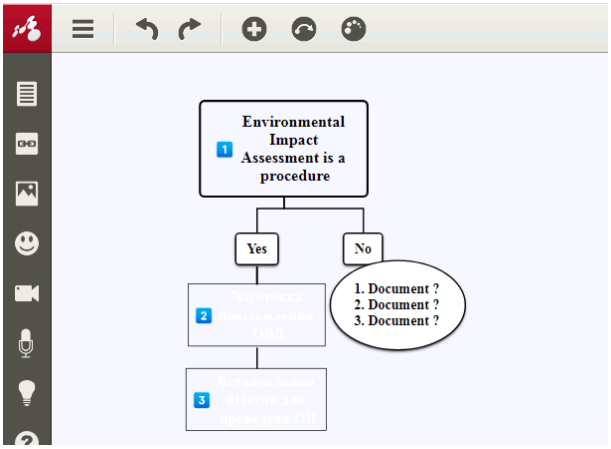

Fig. 8. A model of algorithm construction on the example of the EIA procedure.

Our study also used the didactic resources of Google Drive, which include tools for creating text documents, spreadsheets, presentations, data visualizations. Saving the results of the group project in Google Drive in the suggested by the professor structure was a mandatory and practical work condition, in our opinion (Fig. 9).

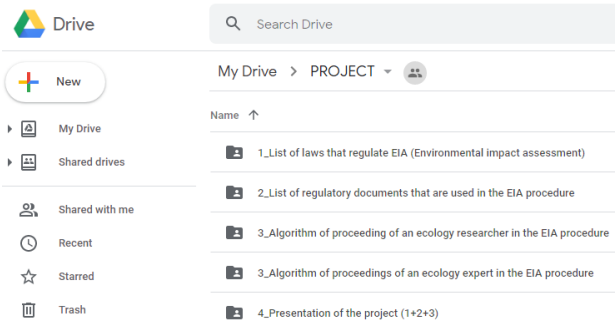

Fig. 9. Tasks for the group project.

The students saved the project on their personal Google Drive and gave access to another group of students who were to evaluate the project using SWOT analysis technology. We find that this method of saving the results has the following advantages:

- auto-saving of the latest version of the document;
- variability when checking the work by the professor (the student could choose how to communicate with the professor: through Google Drive or email);
- the tools to check the notes of several students on the example of a single work by the professor online in Google Drive;
- the ability to mutually analyze the obtained data by multiple users.

One way to present the first folder of the group project was to create an infographic in Easel. It could include a set of pictures of official pages of different state institutions and text blocks from the point of view of their importance for the EIA procedure.

The use of ICT in the study of the "Environmental Impact Assessment" course allowed us to achieve didactic tasks and to form professional competencies for students. It is possible to establish the qualitative performance indicators of the effectiveness of ICT use while studying

the "EIA" course based on the results of the students' performance or the results of the students' survey by questionnaire on the quality of teaching. In TNPU, surveys are conducted anonymously by way of answering the questionnaire.

However, it is difficult to quantify the effectiveness of using ICT in the study of the "EIA" course for several reasons. First, in our view, objective evaluation involves the comparison of students of the control group, the test group, and their performance indicators. Only one group is enrolled in this year of study and it is not advisable to divide it into subgroups for the sake of the experiment (and this is not provided for in the regulatory documents of the Ministry of Education and Science of Ukraine) because of the small number of students (10-20 persons). Taking this into account, a sample of 5-10 respondents will not produce a statistically reliable result and will not be representative. Secondly, it is only the second academic year that this course is being studied (since the EIA procedure has been used since December 2017) and currently the methodology suggested by the authors is tested only by one academic group during the study of the course.

The "before" and "after" test can be used as one of the methods to assess the effectiveness of ICT use and to evaluate the students' performance. The results of such a test will make it possible to assess students' basic skills in using ICT.

We consider the study of the effectiveness of ICT use, as well as the determination of the criteria to assess students' success and the formation of professional competencies as further research.

4 Conclusions and prospects for further research

The training of future ecologists in the context of the transformation of higher education involves the acquisition of knowledge and the formation of skills. One of the ways to achieve this goal is to use information and communication technologies in the process of studying the course by future ecology experts.

The methodology of conducting lessons and preparing a project in the "Environmental Impact Assessment" course, suggested and tested by us, allowed the students to optimize the time spent searching for educational materials, preparing them and making them applicable as much as possible. Each student was given the opportunity to organize their e-synopsis and project simultaneously via using ICT during at lectures and while preparing for practical lessons. In the e-synopsis they constructed an algorithm of actions of an ecologist as a potential researcher or expert in the field of environmental impact assessment, through the use of distinct guidance from the professor, group work during lessons, and independent study.

While studying the "Environmental Impact Assessment" course, students developed skills of using information and communication technologies in lectures and while preparing a group project.

Through the use of the Padlet interactive whiteboard, students gained the ability to adapt and act in new situations when studying the law of Ukraine on environmental impact assessment or discussing its articles.

With the use of ICT during brainstorming at lectures, practical lessons, group assignments, group projects, students were able to practice communicating with experts in other fields of knowledge or activities. By simulating the real-world environmental impact assessment procedure, students developed interpersonal skills that were reinforced by the use of online resources.

Learning the material of all modules of the course, the students acquired the skills to evaluate the impact of technogenesis on the environment through the use of ICT at the stage of studying the EIA procedure.

Examining the learning outcomes showed us that the use of ICT provided students with the ability to use information resources in ecological research for sustainable development goals and individual professional growth.

Positive feedback from students proves the efficiency of using ICT while training future ecologists.

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Conditions for creating a balance between learning styles on the example of the material of the discipline "Ecological Chemistry and Environmental Monitoring"

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Abstract. Aspects of learning styles modelled on R. Felder and B. Soloman are discussed in detail. The results of the study of the educational advantages of students of Kryvyi Rih State Pedagogical University of the speciality "014 Secondary education (Chemistry)" are presented. It is shown that the majority of students in the group are those who study visually, sensitively, actively and consistently. According to studied features of the student's groups didactic material on the theme "Ecological Chemistry of the Lithosphere" of the content module "Ecological Chemistry of Environmental Objects" was elaborated and its role and place in the structure of the educational process determined. Forms of work that involve the use of different cognitive functions are described and therefore contribute to their balanced development. It allows a person to be flexible in the unrestrained development of technological progress, to be open to different ways of obtaining information and perceiving it without resistance and stress.

1 Introduction

Introducing a student-centred model of higher education requires taking into account the subject's preferences regarding the methods of study [1, 2].

According to this approach, one should first understand the preferred learning style of the whole group of students, as well as learning preferences of individual students [3, 4].

It is essential and topical to introduce an individual-centric model in the training of future specialists, who will eventually take the place of a teacher in the student-teacher system [5]. Such an approach will allow students to use their available cognitive functions and improve their gnostic functions and, as a result, to develop in a rapid rhythm of human progress.

The aim of the study was to study the prevailing learning styles of groups of students majoring in chemistry with the subsequent use of acquired knowledge to optimise teaching methods in the process of studying ecological chemistry.

2 Methods

The work was performed at Kryvyi Rih State Pedagogical University. Students of the Faculty of Natural Science participated in the survey to identify the preferred learning styles of all involved students.

Totally 63 persons are first- to fifth-year students; they take undergraduate or graduate courses in the speciality "Chemistry". Senior students studied the integrated course "Ecological Chemistry and Environmental Monitoring". This course fruitfully links theoretical knowledge of chemistry and their practical application.

The instrument, known as Index of Learning Style and developed by R. Felder and B. Soloman (thereinafter Felder-Soloman's model) was used [6, 7]. All respondents were interviewed to respond to 44 questions, which allow one to estimate available preferences in four complementary dimensions.

The instrument categorises individuals in line with their preferences in perception – sensing (Sns in clipped form) or intuitive (Int), information input – visual (Vis) or verbal (Vrb), data processing – active (Act) or reflective (Ref) and understanding of information – sequential (Seq) or global (Glo).

In other words, each of four dimension consists of two opposite styles or a pair of a style and anti-style. They are scored by an 11-point scale. The advantage of one of two opposite styles is estimated on the base of distribution of 11 points between them.

In this paper, the results related to preferred learning styles will be given as percentages indicating the relative number of students in the sample with a particular style. Therefore, the number of students will always be 100% for a given style and anti-style pair.

Consider in detail aspects of learning styles of the R. Felder and B. Soloman model, namely the main characteristics of cognitive functions, if one of the styles

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prevails.

2.1 Sensing and intuitive types of learning

Sensing-type students prefer to learn the facts. They should solve problems using known methods. They do not like difficulties and surprises. So, they will be upset if they receive a question on educational material that has not been covered in detail in a lecture room. Sensing students are also attentive to detail, well-remembered, and do laboratory works, more practical and careful.

Intuitive students prefer theories and hypotheses, love innovation, and do not like repetition. They have a better understanding of new concepts and tend to feel more confident with abstractions and formulas. They work faster and more inventive [7].

Students with a pronounced sensing learning style do not like courses that are not relevant to reality. Intuitive students do not like instructional courses that require a lot of memorisation and monotonous calculations.

The benefits of one or the other way of learning can be strong, medium or weak. Students should be able to act in both ways to be effective in teaching and solving problems. If they favour intuition too much, they may lose important details and make mistakes in calculations and lab work due to inattention. If they rely solely on sensing learning, they will be able to reduce learning to cramming and repetition of known methods, refusing to live experiment and develop creative thinking [7].

Sensory-type students remember and understand information better when they see how it relates to real life. When they study a discipline that contains much of the material in the form of theories and abstractions, difficulties may arise. The teacher should be given specific examples for each concept and methodology and show how these concepts are used in practice to prevent obstacles in learning theoretical problems. If the teacher does not provide sufficient specific data, sensing students should find it on their own or in a textbook, or other texts, or using a joint brainstorming session with their learning colleagues [6].

Usually, intuitive type students take most lectures without problems. However, if such students find themselves in classes where they are primarily required to memorise and mechanically use formulas, they may have problems and boredom. Therefore, the teacher should be provided with interpretations and theories related to the facts studied. If this does not happen, students of intuitive type should try to find regular connections on their own [7].

2.2 Visual and verbal types of learning

Students who have a distinct visual learning style are better remembered for what they see – pictures, diagrams, flowcharts, graphs, movies and visual demonstrations. Verbal students are more likely to receive information in the form of words – written and oral explanations. Both types absorb more when the information is presented both visually and verbally [7].

Most classes use very little visual information: students mainly listen to lectures and read materials written on blackboard and textbooks, as well as manipulative materials. The facts indicate that most students are people with a visual type of perception. In other words, this means that they do not get as much as they could if the visual presentation of data were used more in the class [6].

If the student has a visual type of perception, he/she must independently find diagrams, sketches, diagrams, photographs, graphs, or any other visual representation of course materials, which is predominantly verbal. References to videos, videos of the course will be useful. It is the best for students to use maps or flowcharts where critical points of a theme are depicted in the middle of squares or other figures, with demonstrations of connections between concepts (in the form of a line with arrows between blocks) [6]. For students of the visual type, it is useful to use colour markings of records when each colour has its meaning — for example, highlighting concepts related to the same topic, class, type, etc. [7].

Students of verbal type should write short summaries or translations, of course, materials in their own words. Group work can be beneficial to them. They understand the material better by listening to the explanations of classmates and learn even more when explaining the content to others [6].

2.3 Active and reflective types of learning

Students who have the advantage of an active learning style are better able to understand and acquire new knowledge by doing something with them. Reflective students should first calmly reflect on the information received and only then begin to work with it [6].

The advantage of one type or another may be strong, moderate or weak. It is desired to have a balance of both. If the student always does, and then thinks, at first, he or she may take up the case too hastily, which will create problems. If he spends too much time thinking, he can never do anything about it.

As a rule, active students are more comfortable working in a group, as opposed to reflective students who prefer to study alone. Attending lectures without any movement and physical activity, apart from giving notes, is not easy for both types, but especially tricky for active students [7].

If there is little classroom time when discussing discipline or discussing it together, students with an active type of perception should make up for that. To do this, they need to prepare for a class together with a group of friends to take turns explaining topics to each other. It is useful for them to imagine that they can be asked to the next control and to represent how they will respond [6].

When students have a little time in the lecture room to reflect on new knowledge, persons with a reflexive type of perception should try to make up for the lack of that. To do this, they need not only read and memorise the educational material but also stop from time to time to repeat what they have read and think about possible questions and apply the knowledge they have learned. It is also helpful for them to write small summaries based

on what they have read or taken notes in the audience, presenting the material in their own words. Such an approach requires additional time but will allow better study of information [7].

2.4 Consistent and global types of learning

Students with a predominant sequential learning style gain understanding through successive steps, each of which is a logical continuation of the previous one. Global-type students tend to learn big leaps, gathering information almost haphazardly, and then suddenly grasping the essence [7].

Students with consistent perceptions tend to follow a logical step-by-step search. Students with global perceptions can solve problems quickly and put the pieces together once they have understood the big picture [6].

Many people may mistakenly qualify as "global" because everyone felt astonished by the "illumination" [7]. However, what makes the perception global or consistent happens before the outbreak. Students with a very pronounced global perception who cannot think sequentially may experience severe difficulties until they understand the overall picture [6]. Even when received, they may have a vague idea of the details of the subject. At the same time, consistent students may know a great deal about specific aspects of the subject under study but not understand how they relate to its other components or other matters [7].

Most courses in higher education are taught sequentially. However, if the student has a consistent type of perception, and the teacher moves from one topic to another and misses the logical steps, it may be difficult for the student to keep track of his or her reflections and remember something. One needs to complete the missing steps with the help of the teacher's answers or yourself, referring to the directories. Students should logically arrange the lecture material. To develop global thinking, one must try to relate each new topic to one that has been studied before. The more a student does this, the deeper will be the understanding of the problem [6].

If a student has a global type of learning style, then it will be useful for them to understand their need for a general picture of the subject under study before mastering the details. If a teacher starts a new topic without trying to explain how it relates to what has been learned before, it can cause problems. However, there are steps a student can take to get a total picture faster [7].

Before beginning, the first paragraph of the next section of the text, a student who has a global type of learning style needs to review the section completely to understand a general idea. Initially, this will take extra time, but will subsequently avoid multiple revisions of individual parts [7]. Instead of spending time reviewing each subject for a short time each day, it may be more useful for such students to study topics in large blocks [6]. Students of this type should try to relate the subject under study to what they already know: to ask the teacher to help them see the links or find them in the additional literature on their own. When a student suddenly understands new material and understands how it is related to other topics and disciplines, he/she will be able to apply his/her new knowledge in a way that most consistent students do not dream of [7].

3 Results and discussion

3.1 Conflict of styles

Lecturers have their advantages of learning styles [8, 9]. Most lecture courses are aimed at a small number of people who can perceive and process information intuitively, verbally, reflectively and consistently. Such a situation creates a disadvantage for many students.

Lab work, being inherently sensing, visual, and active, could offset some of the imbalance. However, most laboratory work involves, first and foremost, mechanical exercises. They illustrate only a small part of the concepts discussed at the lectures and rarely provide a significant understanding or development of skills. Thus, sensing, visual, active and global students rarely meet their educational needs when studying at higher education institutions.

The discrepancy between teaching style and teaching style has several serious implications. In this case, the students feel as if the communication is taking place in an unknown foreign language.

These problems can be minimised, and the quality of education can be significantly improved if teachers take into account the particularities of student preferences in teaching styles [10, 11].

It is challenging to create the conditions for the presentation of information in a form that satisfies all possible styles of student learning in one audience. There are different approaches to solving this problem.

The works we have done earlier describe the methodology of choosing methods, forms and teaching aids, taking into account the peculiarities of learning styles of students of different specialities [12, 13, 14]. He has a right to life and another approach that involves applying the techniques of presenting information conveniently to each style for a while.

The development of all cognitive styles is beneficial for students. Therefore, seeking to strike a balance for everyone in the learning process can be helpful. Then students will have natural learning activities available to them, as well as creating conditions for the development of other learning styles. Such a situation can promote active learning and a positive attitude towards it, as well as lead to the development of less developed abilities [15].

When working on the development of a global teaching style, it is better to study the material with the means of visual techniques that are chosen in such a way that students can offer a generalised conclusion from their analysis. To do this, you should first show the schematics of the links of the elements for study, experiments, results, and then allow students to reach the provisions of specific theories independently.

When developing a reflective teaching style, teachers

sometimes need to stop during the lecture to give time to think and formulate questions. You should also schedule small group problem-solving sessions in which group students spend one or several minutes solving any of the many different issues and problems.

For example, such questions as: "Start solving this problem," "What is wrong with what I wrote on the board?" have produced incorrect results: how many possible explanations can you come up with? ".

Also, to develop a global teaching style, it is necessary to demonstrate the logical connection of particular topics, to show the interaction between current material and other topics of the same discipline, other courses and daily life.

Encouraging or engaging in self-help in homework is essential. Students who participate in collective learning, both in and out of the classroom, receive better grades and show greater enthusiasm [15].

3.2 Found preferences in learning styles

Let us consider in detail the results obtained in the study of the learning preferences of all interviewed students (Fig. 1).

A significant difference was observed in three dimensions: Sensing (Sns) (65.7%) / Intuitive (Int) (34.3%); Visual (Vis) (64.2%) / Verbal (Vrb) (33.2%) and Active (Act) (59.5%) / Reflective (Ref) (40.5%).At the same time, no essential difference was found in the fourth dimension of Sequential (Seq) (50.1%) / Global (Glo) (49.9%).

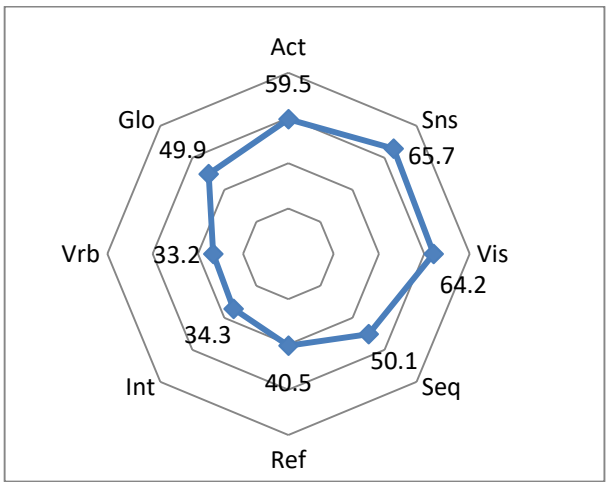

Fig. 1. Preferences in learning styles for students of the Faculty of Natural Sciences of KSPU, the speciality 014 Secondary education (Chemistry).

In other words, style prevails over anti-style in three dimensions. In the fourth dimension, there is a balance between style and anti-style.

Typically, learning style is a relatively stable and weakly variable characteristic of a person, which is formed under the influence of its psychological and physiological characteristics. For example, it was shown in [16] that it is weakly dependent on the year of study for first- to fourth-year undergraduate students.

The opposite view is that dominant learning styles can change under the influence of external circumstances. Such influencing factors may include the field of study and type of material being studied, delivery mode, the age of an individual, his motivation and educational level, etc.

It is also commonly believed that learning styles are not sensing to the student's gender, but may vary significantly between groups of students in different fields of study.

Thus, the question of the stability of learning styles and their dependence on students' gender and age can still be considered debatable. The results obtained in the paper allow us to evaluate the influence of the above factors.

For this reason, the results of testing the learning styles of all students were divided into groups by gender (Fig. 2 and 3).

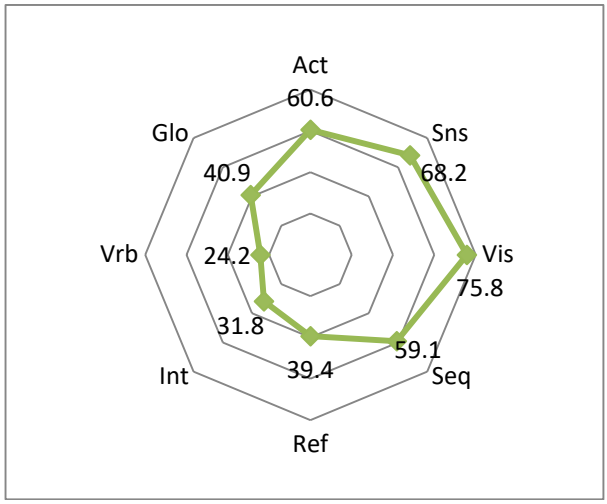

Fig. 2. Preferences in learning styles for male students.

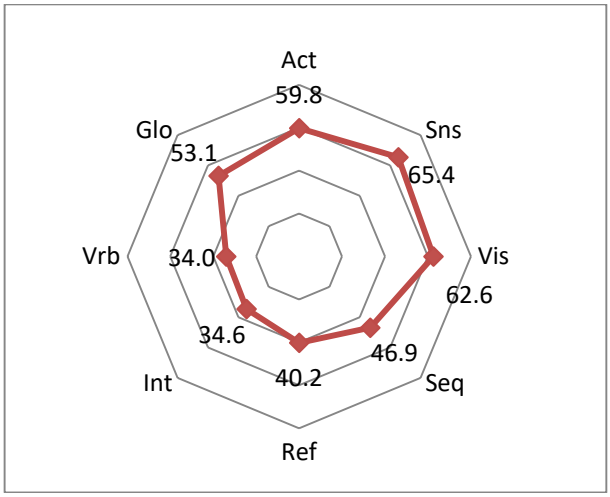

Fig. 3. Preferences in learning styles for female students.

Comparing the results of the two study groups "boys" and "girls", we can see that respondents-boys and respondents-girls have a difference between the two dimensions: "boys" – Vis (75.8%) / Vrb (24.2%), Seq (59.1%) / Glo (40.9%); "girls" – Vis (62.6%) / Vrb (34.0%) Seq (46.9%) / Glo (53.1%).

In two other characteristics, the difference is almost not noticeable: "boys" – Sns (68.2%) / Int (31.8%), Act

(60.6%) / Ref (39.4%); "girls" – Sns (65.4%) / Int (34.6%) and Act (59.8%) / Ref (40.2%).

Also, the results of testing the learning styles of all students were divided into groups by age (Fig. 4, 5).

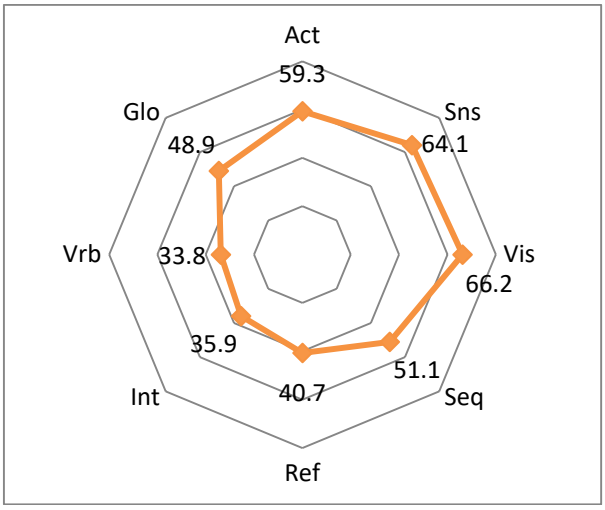

Fig. 4. Preferences in learning styles for students of 17-20 years old.

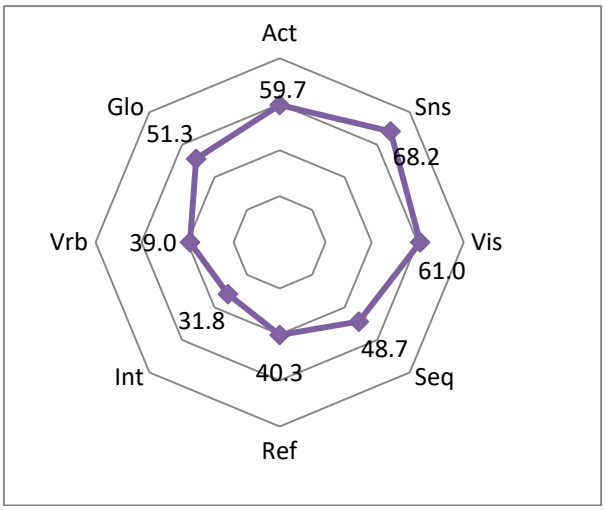

Fig. 5. Preferences in learning styles for students of 21+ years old.

Comparing the results of the two study groups for ages of 17-20 and 20+ years, we concluded that the respondents in these groups had only minor differences.

For 17-20 years, the preferred styles are as follows: Sns (64.1%) / Int (35.9%), Vis (66.2%) / Vrb (33.8%), Act (59.3%) / Ref (40.7%), Seq (51.1%) / Glo (48.9%).

For 21+ years, Sns (68.2%) / Int (31.8%), Vis (61.0%) / Vrb (39.0%), Act (59.7%) / Ref (40.3%), Seq (48.7%) / Glo (51.3%).

In our opinion, there is a slight difference in the respondents' learning styles because all the respondents' study in the same speciality.

3.3 Optimisation of teaching methods to study ecological chemistry

Taking into account the obtained profiles of educational advantages in groups, we have prepared a didactic material on the topic "Ecological chemistry of the lithosphere" of the content module "Ecological chemistry of environmental objects". The role and its place in the structure of the educational process are determined. Most students in the group are those who study visually, sensitively, actively, and consistently. That is why we used in the lecture the methods, forms and teaching resources that are well percept by them.

Example:

• a large amount of multimedia presentation data was used for visual perception of information during the lecture;
• for the of sensing data processing, lecture information was provided based on life stories and situations;
• to attract an active component of the training types, several problematic situations on this topic were created. Students worked in small groups for several minutes over their decision;
• a link between current material and everyday life was demonstrated for the consistent component.

For the lecture information on the following processes was elaborated: soil formation, weathering and its varieties, leaching, gouging, salting and others, as well as learning about the participation of living organisms in soil formation.

Submission of material on fundamental processes in the lithosphere was also adapted to the prevailing stylistic characteristics of students, namely: visual, sensing, active and consistent, but other techniques have already been used. Example:

• a multimedia presentation with various diagrams and photographs illustrating the content of the theme was used for visual stylistic characteristics during the class;
• for the sensing style, the information of the lecture was related to the environment, which is directly an integral part of human life;
• for the active component, lectures specifically made mistakes in the content and provided an opportunity for students in small groups (2-3 people) to consider where the inaccuracy was made;
• for a consistent component, the connection between current material and everyday life was demonstrated.

During the laboratory session, we formed practical knowledge about the composition of the soil and some of its indicators. For this purpose, the following methods were applied:

• illustrations of the mechanical composition of the soil, video of bean growth, and instructions for planting it in the soil were used simultaneously with the parallel text that described these processes to learn by visual style during the laboratory work;
• for the sensing style, the information related to the fertile surface layer of the lithosphere, which is directly connected with human life, was provided. Students were asked to find signs that determine the quality of the soil and its use in human activity;
• an analysis of soils in which beans grew was used for the active style of the students in the laboratory. Students worked in small groups analysing soils.

The content of students' independent work included tasks that, in our opinion, are intended to help develop a

global, reflective, verbal, intuitive styles of learning activity.

Here are examples of the tasks of students' independent work. To develop a global characteristic of the Seq/Glo pair of learning styles, students were invited to do the following: "Use the guides, the Internet, and other recommended sources to learn about the content of the Ecological Chemistry of the Lithosphere. Determine the importance of chemical processes in soils for the formation of biogeochemical cycles of chemical elements and their substances in the nature of our planet".

To satisfy of the reflective style of learning of the Act/Ref aspect, we asked students to do the following: "Using lecture notes, read the study material, occasionally pausing to repeat what you have read. Write small abstracts based on what you have read. What is the main source of pollution of the lithosphere? Describe the main components of the emissions from such a source and the effects of their influence on the chemical composition of the fertile soil layer. What are some ways we can deal with the primary and re-contamination of key areas?"

To satisfy the requirements a verbal style in the Vis/Verb pair, we asked students to do the following task: "Using the above text, make a diagram of the biogeochemical cycle of Carbon.

Carbon in nature:

The chain of carbon atoms is the basis of all organic matter: proteins, fats, carbohydrates and other compounds that are necessary for the life of all living organisms.

The Carboniferous circulation between wild and inanimate nature occurs at high speed. The main inorganic compounds of Carbon are its oxides (CO_2 and CO), as well as carbonate that makes up carbonate rocks.

The most mobile Carbon compound in the atmosphere, which plays a significant role in the cycle, is carbon dioxide (CO_2).

Carbon's central reserve is concentrated in Carboniferous rocks (carbonates, dolomite, etc.) at the bottom of the ocean and in the Earth's crust, as well as fossil fuels. Carbon reserve in the atmosphere is much smaller. However, it plays a significant role in the cycle due to its mobility.

As a result of the relatively small reserves in the atmosphere, the Carbon cycle is more vulnerable than the Nitrogen cycle.

Recently, the carbon dioxide content in the atmosphere has been steadily increasing, indicating that the equilibrium processes in the biosphere are disturbed. The reason for this is human economic activity: high carbon dioxide emissions from burning fossil fuels, reducing forest area, pollution of the oceans, and therefore decreasing photosynthesis intensity – carbon dioxide binding. Increasing carbon dioxide content is the main cause of the greenhouse effect and an increase in the average temperature on the planet".

For the development of intuitive style in the subsystem Sns/Int, we proposed students to do the following task: Tailings form a large amount of dust under the influence of wind flows, which leads to the pollution of atmospheric air and its deposition in large areas of land. Suggest a plan for minimising dust generation.

Thereby in the course of the study, we started to introduce students to different forms of work that involve using the different cognitive functions, and therefore contribute to the development of their balance. The latter, in turn, allows a person to be flexible in the unrestrained development of technological progress, to be open to different ways of receiving information and perceiving it without resistance and tension.

Students, as a whole, evaluated the completed tasks at a high level, which indicates that the students' perception of new tasks is positively fulfilled, without sabotage.

Conclusions

So, in the course of the study, we started to introduce students to different forms of work that involve different cognitive functions, and therefore contribute to the development of their balance. The latter, in turn, allows a person to be flexible in the unrestrained development of technological progress, to be open to different ways of receiving information and perceiving it without resistance and tension.

The prospects for future research

Preliminary diagnosis of students' styles in the group allows the teacher to create conditions for enriching students' stylistic behaviour, which will increase the productivity of their intellectual actions.

The use of the educational resources that are created in this work will help to prevent the occurrence of "conflict of learning styles" of teachers and students during classes.

The findings of the paper can be used in the educational process at higher education institutions to teach the disciplines of the pedagogical cycle. For example, "Methods of teaching chemistry in a specialised school and vocational education institutions", as well as professional disciplines "Organic chemistry", "Computer statistical processing results" and others.

Continuing experiments to establish links between students' academic performance and the development of their cognitive styles is a promising area of research. Summarising of their results will help to formulate principles for the organisation of efficient training of future chemical specialists.

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Majority values of school biological education in the context of education for sustainable development

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Abstract. The idea of the study is that the value potential of the subject is a fundamental element of the knowledge system as part of the realization of the idea of sustainable development in education. The basis of the study used the classification of value categories proposed by Milton Rokeach in 1979. We found that in the main school, the content of the subject "Biology" is primarily aimed at forming ideas about terminal values – "life", "health", "nature"; in high school – about terminal values "life", "health", as well as instrumental values – "perseverance". The value ideas of a biology teacher are one of the key factors in the formation of students' value ideas. In the structure of value representations of biology teachers, the three leaders are orientations towards terminal values. We have put forward the assumption that there is a dissonance between the value ideas of respondents and the values that the school biology course is aimed at forming an idea about.

1 Introduction

At the 70th session of the UN General Assembly, the 2030 Agenda for Sustainable Development was adopted. It includes 17 new global goals that will be included in the subject field of education for sustainable development [1].

According to the Incheon Declaration [2], education is considered as the main driving force for transforming people's lives and achieving sustainable development goals. We are talking about the development of skills, value orientations and behaviours that enable citizens to lead a full, healthy life, make informed decisions and respond to local and global challenges through education for sustainable development and education in the spirit of global citizenship [1].

Education for sustainable development is an international vector of education and enlightenment of a person throughout his life, which is implemented in the interests of human capital development, in order to preserve the cultural and natural heritage of the planet for generations [5].

There are several models for the implementation of education for sustainable development: natural science, interdisciplinary and school-wide [3]. In the framework of the natural science approach, education for sustainable development is considered the successor to environmental education, i.e. teaching the subject "Ecology" [3].

On a global scale, changes in educational systems aimed at adopting the idea of education for sustainable development have been taking place since the early 2000s [1; 3].

The transition to new state educational standards and programs in high school in Ukraine from the academic year 2018/2019 was marked by dramatic changes in the content of the natural sciences educational sector and the biology subject in particular.

Firstly, the name of the subject has changed – "Biology" has turned into "Biology and Ecology".

Secondly, the field practicum was removed from the program.

Thirdly, the principle of functionality has been applied to structuring the content of the subject to replace the principle of hierarchy.

The last two changes require clarification. A field practicum in the previously existing program was provided for a profile level of the subject study, included topics of environmental content and was aimed at developing practical skills of high school students to use bioecological research methods. The principle of hierarchy reflected the phylogenetic sequence of the emergence of living levels, corresponded to the stages of cognitive activity of the student in the formation of high-level generalizations: "biosphere", "noosphere", "technosphere", "living matter", V .I. Vernadskyi and others.

The above-mentioned changes are carefully considered as the movement towards the implementation of the idea of sustainable development in school biological education. Effectiveness of the change can be measured over time.

Today, education for sustainable development has two methodological problems [4].

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The first is connected with scientific foundations, since a classical scientific school cannot fully meet the principle of scientificness in modern conditions [4].

The second methodological problem is the futuristic prognostic nature of education. The growing capabilities of information technology in an irrepressible progression require students to learn how to predict the future steps ahead.

Therefore, it is relevant not only to teach to analyze and draw conclusions, but to predict, envisage the future, and model the activity in the long run. Another difficulty in the formation of education for sustainable development is called the blurring of its content: knowledge, methods of activity and value-semantic attitudes [5].

The concept of "sustainable development" is twofold.

On the one hand, sustainability provides stability, fundamentality, in a certain sense stagnation. On the other hand, development is based on transformation, change, improvement.

Out of this we conclude that a system that is in a state of sustainable development includes unchanged or hardly changed fundamentals and permanent deviations, summarizing as a result in a new quality. What constitutes an unshakable foundation, and what is subject to changes in the framework of science education for sustainable development in general and biological in particular, these questions have to be answered.

The effectiveness of any educational system is evaluated according to the final result. According to the culturological theory of the education content, the results of education are knowledge, reproductive experience, experience in creative activity, and experience of an emotional-value attitude to the world [6]. The need to address just this theory when designing the content of education for sustainable development is indicated in a number of studies [5].

A school subject is a didactically adapted system of scientific knowledge about the world and a person's place in it. The volume of scientific knowledge is growing exponentially, therefore knowledge is the most dynamic element of the system.

In the framework of the study, we consider the experience of an emotional-value attitude to the world as the most constant, long-forming and system-forming element of the knowledge system. We consider the formation of an emotional-value component by means of school biology as one of the strategic goals of education for sustainable development.

The experience of an emotional-value attitude to the world involves the formation a schoolchild's set of value ideas that guide him in the present and future. At the same time, a personal experience of an emotional-value attitude to the world is formed [7].

The value ideas that make up the personal experience act as regulators of behaviour and factors in the choice of a particular model of action. At the same time, they are the result of a person's assimilation of social and cultural-historical experience.

The selection of the content of a school subject aimed at the formation of value ideas among schoolchildren is based on the value potential of biological science: its cultural and historical component [8], current and future prospects for the development of not only basic science, but science as a whole as part of culture.

The transformation of the value potential of a subject into value ideas of students occurs with the direct participation of a teacher who acts as a mediator between the content of the subject and the emotional and value sphere of the student.

The process has a subjective colouring, because it is based, firstly, on the teacher's understanding of the value meanings of the educational process in general and the educational process in biology in particular, and secondly, on the teacher's personal value ideas.

At different stages of ontogenesis, different values have unequal relevance, which is due to a change in leading human activities.

The chronological principle of constructing a system of values is that values of an earlier age acquire a subordinate position with respect to values of a later period [9].

In the context of science education for sustainable development, such a change has other reasons – there is a constant change in the substantial and process content of academic subjects. These changes are caused not only by regular age-related changes in the cognitive activity of students and the concentration of the subject content around generalizations of science in high school compared with the main school in one cycle, but also by a change in the approaches to the selection and structuring of educational content from cycle to cycle in historical terms.

In the framework of education for sustainable development, the selection of the "knowledge" component of the content of education is a mandatory step, since it helps to prevent the blurring of its subject matter and turning it into simple information about the problems of sustainable development [5].

The purpose of the study is to study the state of the issue of the formation of value ideas in students by means of the subject "Biology".

Object of research: value ideas of students. Subject of research: factors in the formation of value representations of students by means of the subject "Biology".

In order to study the current state of the issue of values formed by means of school biology at this stage of the development of natural science, and more specifically, biological school education in the context of the idea of sustainable development, we conducted a study. During it, it was planned to establish a majority structure of values formed by participants in the educational process in primary and high school; identify the factors of its formation.

2 Technique and methods

The study included theoretical and experimental stages.

The theoretical stage was aimed at solving the following problems:

1) to distinguish between the categories of "value", "value representations of the individual", "value

potential of the subject", "value potential of basic science";
2) to differentiate the value representations of a personality according to the subjects of the educational process into "value representations of a student" and "value representations of a teacher";
3) to simulate the process of forming value ideas of students in the framework of the subject.

Methods used at the theoretical stage: analysis of scientific publications concerning formation of students' value ideas, according to the methodology for evaluating the value ideas of an individual.

For the experimental stage, we developed a poll-questionnaire. It included questions to study respondents' attitudes to 11 value categories that belong to two types [11]: terminal (life, health, beauty, nature, equality) and instrumental values (kindness, striving for truth, freedom, perseverance, justice, creative an approach).

The questionnaire was designed for future biology teachers, whom we consider as a connecting element in the process of transforming the value potential of a subject into value ideas of students. In 2019, 40 students of the Pedagogical University of the specialty "Biology" took part in the survey. The questionnaire was aimed at solving such problems:

1) to establish the majority structure of the school biology course values (poll questions 1, 2, 3, 7, 8, 9);

2) to establish the majority structure of the value representations of future biology teachers (poll questions 4, 5, 6).

3 Results

3.1 The results of the theoretical stage of the study

We adhere to the approach according to which value is "a firm conviction that a certain mode of behaviour or the ultimate goal of existence is preferable from a personal or social point of view than the opposite way of behaviour, or the ultimate goal of existence" [12].

Values have a hierarchical nature, because, unlike norms, they are a system: a personal system of values, a system of values of a society, a professional system of values [9]. The hierarchical structure of values also determines that the value system itself should reflect the general properties of hierarchical systems [9]. Speaking about the concrete-applied significance of axiology in the school educational process, and therefore about the concrete embodiment of the idea of sustainable development in education, it is important to solve a number of issues. For example, should a system of values formed by means of a subject of biology, chemistry, ecology reflect the properties of biological, chemical, ecological systems? Or should one proceed from such general properties of systems as integrity, emergence, subordination, reliability, adaptability, etc., irrespective of subject matter?

In the latter case, the value systems formed in the educational process when studying different educational subjects of the natural science cycle are characterized by the same properties with different content. More specifically, the problem can be formulated as follows: are terminal values such as life, health, nature – the values formed by the means of all subjects of the natural science cycle or only biology?

The study of this question will give an answer about what values, value ideas should be formed in the light of implementation of the idea of sustainable development in education when studying the subjects of the natural science cycle individually and as a whole. Let us note that there are successes in finding the answer to this question. Education for sustainable development should be subject-related [5; 10; 13]. Within each subject-oriented invariant (ecologically-centred, economically-centred) a varied content is built taking into account the local educational and cultural context. The subjectivity of education for sustainable development helps to prevent the blurring of topics identified by UNESCO as priority within the main topics of discussion in education for sustainable development [14].

In the model constructed around the "ecological imperatives" invariant, the personal meanings of the ecological imperative are the system-forming factor in the content of education for sustainable development [5].

We found that in literature the concepts of "values", "value orientations", and "value representations" are often confused. The latter are not reducible either to values, as really acting immanent regulators of human activity, or to value orientations, as conscious representations of a subject about his own values.

Value representations of a personality are a complex dynamic category, including its value orientations, value ideals, value stereotypes, value retrospective, etc. [12].

The valuable potential of an educational subject is the subject content, which reveals the social and personal significance of the material being studied.

The valuable potential of basic science is the totality of objective knowledge about social and natural reality, the leading motive for which is the need to know nature, rather than gaining control over natural objects [15].

In the course of solving the second and third tasks, we came to the conclusion that:
- teacher's value ideas are factors of the formation of students' value ideas;
- formation of teacher's value ideas that are adequate to the modern level of science, society and culture development, is one of the tasks of his professional training;
- the process of forming students' value ideas within the framework of a school subject looks like this: "value potential of basic science" → factors of selecting the content of education → "value potential of a school subject" → "value ideas of a teacher" → "value ideas of a student".

3.2 The results of the experimental stage of the study

The content and results of a survey conducted at the experimental stage are given below (Fig. 1-4).

1. Do you agree that the content of the subject "Biology" is aimed at the formation of value ideas of students?

Results: a) clearly "yes" – 63%; b) more likely "yes" than "no" – 28%; c) rather "no" than "yes" – 9%; d) clearly "no" – 0%.

2. Is the content of the subject "Biology" in the basic school, in your opinion, aimed at forming ideas about what values? Arrange them in descending order: kindness, life, health, aspiration for truth, beauty, nature, freedom, equality, perseverance, justice, creativity.

Results: nature – 86%, life – 74%, health – 74%, beauty – 20%, creativity – 6%, freedom – 6%, kindness – 6%, equality – 3%, striving for truth – 3%, perseverance – 3%, justice – 3%.

3. What values creating is the content of the subject "Biology" in high school, in your opinion, aimed at? Arrange them in descending order (the options are the same as in question number 2).

Results: health – 54%, life – 49%, perseverance – 46%, nature – 40%, striving for truth – 17%, beauty – 11%, equality – 11%, creativity – 9%, justice – 9%, freedom – 6%, kindness – 3%.

The results of the answers to questions 2 and 3 are summarized in figures 1, 2 and 3 (dark line – basic school results, light line – high school results).

4. Arrange the values in order of decreasing their priority for yourself (the options are the same as in question No. 2).

*Results**: life – health – nature – perseverance – justice – equality – freedom – beauty – kindness – creativity – striving for truth.

5. Select three synonyms for the word "valuable" from the list: expensive, long-awaited, deserved, promising, useful, pleasant, fair.

Results: expensive – 49%, long-awaited – 31%, well-deserved – 37%, promising – 29%, useful – 60%, pleasant – 20%, fair – 20% (results are presented in figure 4).

6. Rate the following statements (I agree with – the "+" sign, I do not agree with – the "–" sign):

a) valuable is what is important and useful for me – 86%;

b) valuable is what is important and useful for my loved ones – 86%;

c) valuable is that which is important and useful for society – 74%;

d) valuable is that which is important and useful for nature – 94%.

7. Arrange in order of decreasing significance the factors of influence on the formation of the student's value ideas: friends; society; the content of the educational material (information from the history of science: famous personalities, their lives, views, successes, history of discoveries); a family; school (teacher).

*Results**: family – friends – school (teacher) – society – content of educational material.

8. What do you think is the object of value meanings in modern school biological education in general: society, nature, people.

Results: a) society – 9%; b) nature – 62%; c) people – 29%.

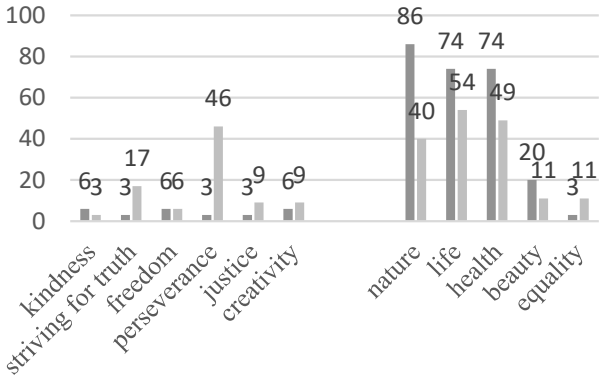

Fig. 1. General results on the selection of values of a school biology course.

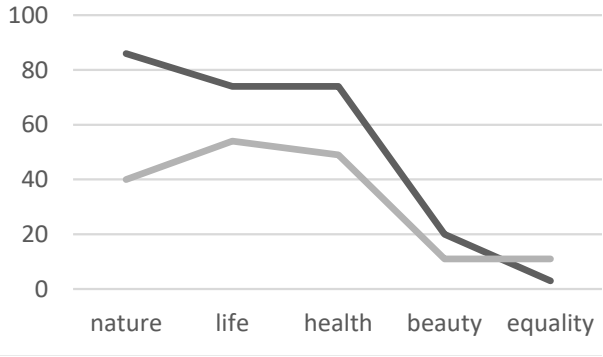

Fig. 2. Majority system of terminal values.

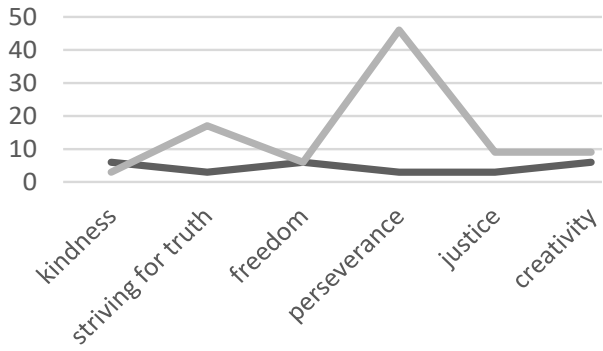

Fig. 3. Majority system of instrumental value.

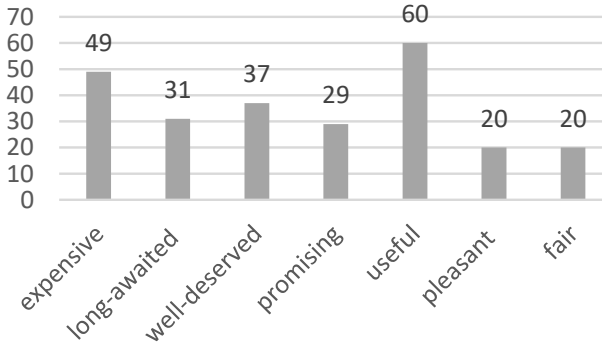

Fig. 4. The respondents' choice of synonyms for the word "valuable".

9. Arrange the objects of value meanings in order of decreasing importance for humanity as a whole: a) society; b) nature; c) a person.

Results: nature – man – society – 40%; man – nature – society – 26%; man – society – nature – 17%; nature – society – man – 14%; society – man – nature – 3%; society – nature – man – 0%.

* *Note*: the answers are ranked according to the principle of majority, that is, the correspondence of the significance of the value to the frequency of its choice – from the most significant category to the least significant one.

4 Conclusions

1. In the basic school, the content of school biology is primarily aimed at the formation of ideas about terminal values – "life", "health", "nature".

2. In high school, the content of the subject is primarily aimed at the formation of ideas about terminal values – "life", "health", as well as instrumental value – "perseverance".

3. In the biology course of high school, as compared with the basic one, the orientation toward the formation of ideas about the terminal values of "life", "health", and "nature" decreases.

4. In high school, the focus is on the formation of ideas about instrumental values "striving for truth" and "perseverance."

5. In general, the school biology course is more focused on the formation of ideas about terminal values than instrumental ones.

6. The results can be considered as confirmation of the chronological principle of building a system of values in ontogenesis.

7. In the majority structure of value ideas of future biology teachers, the three leaders are orientations towards terminal values: life, health, nature.

In the course of an experimental study, it was found that such instrumental values as a creative approach and the aspiration for truth do not find a worthy representation in the majority list of value ideas of respondents.

On the one hand, such a result is relevant, on the other hand, it is not very charitable from the point of view of a positive assessment of the readiness of future teachers for professional activities for the implementation of sustainable development ideas in biology education.

The majority structure of the selected synonymous terms (task 5) demonstrates that the respondents attribute to values the following: firstly, something having a utilitarian focus (valuable – useful), secondly, something which is expressed in significant material equivalent, and thirdly, something which involves the application of certain efforts.

5 Outlook

Further areas of research we see in:

- establishing the causes of the revealed differences between the value potential of the subject "Biology" and the value ideas of the participants in the educational process, that is, between their declared and real values;
- elucidation of the nature of reflection of differences in the fulfilment by teachers of biology of professional activities in the framework of education for sustainable development;
- the study of the ratio of declared and real values (value ideas) of students;
- study of the microstructure of personality value representations of a biology teacher and a student studying biology (value orientations, value stereotypes, value ideals, etc.);
- modelling the process of value ideas formation of a biology teacher as a factor in the formation of students' value ideas solving the problems of education for sustainable development;
- modelling the process of forming value representations of students' personality by means of school biology in the framework of education for sustainable development.

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Natural science education concept for sustainable development

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Abstract. The article is revealed essence and the concept of "ecological and evolutionary approach", conceptual ideas of ecological and evolutionary approach (the idea of evolution and the idea of ecocentrism) are disclosed. Author determined methodological principles of ecological and evolutionary approach to teaching. The concept of teaching natural sciences on the basis of ecological and evolutionary approach and didactic principles of implementation of ecological and evolutionary approach to the teaching of natural sciences (didactic conditions, principles and laws) are developed and scientifically substantiated which is visualized in a didactic model of teaching natural science on the basis of ecological and evolutionary approach. The technology of teaching biology based on ecological and evolutionary approach is developed. Results of pedagogical experiment proved the effectiveness of the technology of teaching biology on the basis of ecological and evolutionary approach and the conception and implementation of teaching principles of ecological and evolutionary approach to the teaching of natural sciences embodied in it.

1 Introduction

The global issues determining the future prospects include society, humanity and nature in their interrelation and interdependence. Today the fact that there is a real threat of environment balance upsetting as the result of unrestrained anthropogenic activities is indisputable. It is evidenced by numerous modern environmentalists' researches whose works prove environmental degradation in Ukraine: soil depletion, rivers and lakes pollution, ecosystems degradation, etc.

Current environmental situation requires an immediate resolution. That is why the search for effective environmental problem solving and, consequently, ways to harmonize the relations between society, human and nature becomes urgent and expedient. Currently Land (1992), Forest (1994) and Water (1995) Codes, a number of laws concerning the protection of the natural environment are effective in Ukraine, and a National Environmental Policy Strategy up to 2020 has been developed. However, it is necessary to find effective ways of the existing environmental problems elimination and new one's prevention.

The current stage of human interaction with nature is characterized by a significant aggravation of local, regional and global environmental problems (natural environment negative changes, populations gene pool disruption, natural resources depletion) leading to human life and health deterioration. These problems are of social character as they are caused by human activity, people's attitude towards nature in accordance with their social development. The idea that it is possible to stop the ecological crisis escalation only if they rethink their behavior culture and maintain the balance in nature should be established in the minds of people. We see the way to ecological culture, consciousness, thinking that have become a necessary condition for the harmonious and environmentally safe society development at the turn of the second and third millennia in quality science education.

2 Purpose

The purpose of the study is to explore the nature, content and conceptual ideas of an ecological-evolutionary approach to the natural sciences teaching for the sustainable development of society. In order to achieve this goal the main study objectives were defined: 1) to reveal the content and scope of the concept of "ecological-evolutionary approach" on the basis of philosophical, ecological, pedagogical and natural-scientific literature review and collation; 2) to establish scientifically the ideas of evolution and ecocentrism as conceptual frameworks of sustainable development education; 3) to reveal the basics and to explain the meaning of ecological-evolutionary world view; 4) to experimentally test the pupils' ecological-evolutionary worldview formation as a result of learning on the basis of ecological-evolutionary approach.

3 Discussion

The main goal of civilization development is to provide eco-evolution (joint, concerted, nature-aligned development) of humanity and biosphere [1]. In the 21st

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century humanity has brought planetary civilization to crisis. The way to its overcoming is in the mastery of holistic thinking in accordance with the laws of nature and leading to ecological culture.

Above all, the intellectual potential should provide the society transition to safe sustainable development requiring qualitative transformation of people themselves who would obtain the capacity for a global worldview. The understanding of the relation between the development (evolution) of society and ecological problems, people's dependence on nature and its development and not vice versa should be established in the mind of modern human, filling us with the hope for global catastrophes prevention, the biosphere stability loss above all [2].

School, education, society should prepare a person able to live in a global space. That is why we believe that the crisis phenomena in society resulting from its negligence can be overcome through the formation of a person of a new type – the person of the future.

L. Rybalko defines the person of the future as educated, cultured, morally developed, able to undertake competent responsibility for new social progress directions, for the environment safe condition. The author wrote: "Actually as well as the whole world Ukraine is expecting a new era and simultaneously it is searching for a social, economic and scientific-technical survival platform, a new paradigm of a person's preparation for life that would provide not only an adaptive approach to reality but also harmonious development of reality itself in accordance with human life dimensions dictated by the ideals of the 21st century" [3].

O. Topuzov emphasizes the role of education in the sustainable development of society in his works: "A mature personality, fully ready for life, able to act independently, make decisions, discern between good and bad, form relationships with different people and objects of nature in accordance with their own life positions, find the necessary information and use it successfully, building their mentality" [4].

Scientific education determines the level of society development, ways and means of environmental, economic, cultural problems solution and, ultimately, provides the citizens' life quality. In modern times humanity is facing three global problems: environmental, associated with the provision of biological balance of human and nature amidst the global environment pollution, techno-economic, associated with the planet's natural resources depletion, and socio-political. They may be solved only by the sufficiently theoretically trained experts possessing the fundamental planetary ecological worldview, familiar with the basics of modern natural science and ecology. The latter is provided by school science education and higher education establishments. At all times of human development natural and scientific knowledge formed the basis of the scientific worldview, because as a system of scientific knowledge about nature they revealed the universe structure and contributed to the knowledge of the fundamental laws of nature characterizing the holistic picture of the world of any era [3].

I. Ilyin [2], M. Romanenko [6] et al. tend to believe that the new educational system should be built on the principles of education for sustainable development forming the modern scientific worldview. We share their opinion that the primary task of education is to create a human consciousness contributing to the civilization survival. The only way of the transition to the society sustainable development is to form an "advanced consciousness", especially for the younger generation. Such consciousness will advance the existence – that's the essential factor for the effective and timely society transition to sustainable development leading to the harmonization of human relations with nature.

The conceptual ideas, their scientific validation and application in the content of science education in order to promote education for sustainable society development are required.

4 Research results

We regard the ecological-evolutionary approach in science education as a modern general scientific direction in the methodology of nature and its objects cognition as holistic systems with the explanation of their ecological relationships, evolution and their sustainable development prospects forecasting [4].

The ecological-evolutionary approach in the science education content is regarded as a social and pedagogical problem simultaneously. We associate its social content with the necessity for the human development harmonization, particularly the need to overcome global environmental problems, the transition from spontaneous human impact on nature to the conscious, purposeful interaction with it evolving deliberately. Such interaction is possible with a sufficient level of ecological competence including ecological culture, consciousness, thinking formed in each person. The pedagogical content of the problem is associated with the need for conceptual changes in the school science education content on the basis of society sustainable development implying the development of the pupils' holistic knowledge about nature, key natural science competence, value attitude to nature and appropriate behavior in the environment.

The content of the ecological-evolutionary approach is determined by the conceptual ideas of evolution or development and ecocentrism.

The application of the idea of evolution in the content of science education allows to reveal the nature evolution at equal levels of arrangement of matter, to establish the cause-and-effect relations and to provide internal dependence between the studied objects. The idea of ecocentrism as the worldview ideology of ecological attitude toward nature, environmental protection pursuant where to nature is regarded as a value independent of human preferences prioritized to the goals and needs of humanity provides the knower's comprehension of the connections between society and its natural environment, between the animate and inanimate nature objects as well as the ways of biosphere development and humanity survival [3].

The implementation of the idea of evolution together with the idea of ecocentrism in natural sciences teaching allows to show the pupils that the organic world has been evolving towards the natural systems structure complication corresponding to the adaptive capabilities and environment specificity, illustrates the related links between different natural objects, explains the nature development patterns, the interrelations between its systems advancing the nature integrity understanding, ecological thinking culture, value attitude towards nature and corresponding behavior in the environment formation in the young generation.

It was stated that the application of ecological-evolutionary approach in the natural disciplines teaching makes it possible to realize that any organism including human independently forms its living environment, provides its stability creating optimal conditions for its existence; that the biosphere stability depends on its integrity and safe development.

The study revealed that the conceptual ideas of the ecological-evolutionary approach (evolution and ecocentrism) have a long generation history and appear relevant in the modern scientific dimension as their development in natural science led to the formation of a modern concept of global evolutionism as a system of notions of nature development process in all its various natural-historic forms: the evolution of the Solar System and the Universe, chemical evolution, the Earth evolution, biological and social evolution.

Thus, the conceptual ideas of ecological-evolutionary approach (the idea of evolution and the idea of ecocentrism) are dictated by the complex nature of the environmental problems that should be addressed to at the intersubject level. They are used in various scientific fields (philosophy, biology, geography, psychology and pedagogy) that proves their relevance, as environmental problems are of a global character and are rooted in the human life spheres covering worldview systems, social norms, ethnic, human relations, culture in general. Only a highly educated and highly spiritual society is able to implement the principle of co-evolution with nature that is a common, co-ordinated development. For the formation of such a society and its sustainable development achievement a new approach to the content of education (school and higher) characterized as ecological-evolutionary is required.

The essence of natural scientific cognition on the basis of ecological-evolutionary approach consists in: the nature evolution revelation; establishment and explanation of cause-and-effect relations of the objective reality systems functioning, their evolution on the basis of the laws of development and the laws of ecology; the desire to reveal the harmony of the universe, the harmony of relations between human and nature; affirmation of the interconnection of society and nature, human and their environment, understanding that both society and nature evolve together as a single process of co-evolution (co-evolution is regarded as a form of joint development of two systems (social and natural) that does not lead to their destruction but provides ensures their harmonious existence).

The ecological-evolutionary worldview resulting in the ecological competence, ecological consciousness and ecological thinking formed in the person should become the nucleus of the new human ecological paradigm and ecological culture.

The ecological-evolutionary worldview (EEW) is explained as an evolving system of principles, views, knowledge, values, assessments, beliefs, practical guidelines determining a person's holistic comprehension of the unity of natural and social being, their co-evolution, governing the person's attitude towards the environmental problems and their solutions, form an active environmental viewpoint, encourage environmental activity and the biosphere development stability preservation. Such worldview type is peculiar to an environmentally educated person mindful of nature and involved in environmental management improvement. We consider such worldview type as a multidimensional integral component of the person's intellectual and spiritual culture providing their creative self-realization in environmental problems solution including responsibility for the state of the environment, the presence of ecological views and beliefs, experience in the natural environment studying and protecting.

The EEW formation contributes to the person's realization of the cause-and-effect relations between animate and inanimate nature, between nature and human, to the understanding that both nature and human evolve and these processes should occur in a coherent manner as co-evolutionary development. Human should build their relations with nature only on a scientific basis in order to predict the consequences of their activity and to regulate them without harming the nature, without disturbing its internal ecological balance and harmonious interrelations with society. It requires deep and comprehensive natural-scientific knowledge about the object of research, identification and realization of the patterns and tendencies of nature and society development constantly occurring under the influence of numerous natural-geographical, socio-economic, socio-organizational factors, adequate application of scientific research methods. That is why we believe that the EEW may become the guide sign directing modern civilization to the harmonious relations with nature, the awareness of the unity and interdependence of humanity and nature.

The EEW presence in a person means the ability to solve the environmental problems of society and nature, to show the behavior that does not result in the biosphere destruction but contributes to its development, to understand the necessity for the interconnection of humanity and nature, to recognize the objective ecological and evolutionary relationships and their interdependencies.

The components of ecological-evolutionary worldview are intellectual, emotional-value and activity (Fig. 1).

The intellectual worldview component is represented by scientific and environmental knowledge playing the key role in the cognition of objective, historical and ecological realities. It is the knowledge of nature and human, understanding of the prospects of development of relations between society and nature; of the co-evolution

of nature, human and society; understanding of the biosphere development stability dependence on human activity. All of this forms the young person's critical thinking corresponding to certain outlook, worldview and world perception, as shown in Fig. 1. Ecological knowledge as part of human cultural achievement support ecological ideal characterized by the mind covering the entire planet. Herewith the person becomes a consciously creative creature able to change the external world and their own nature with a high environmental culture. In modern times human relations with nature are far from ideal and require rethinking, as they often result in environmental problems. The high level of development of social consciousness, scientific ecological thinking, human ability to make decisions and act planetwide direct the ecological state of reality to the ideal. We believe that through environmentalization of the education content based on the idea of ecocentrism is required for that.

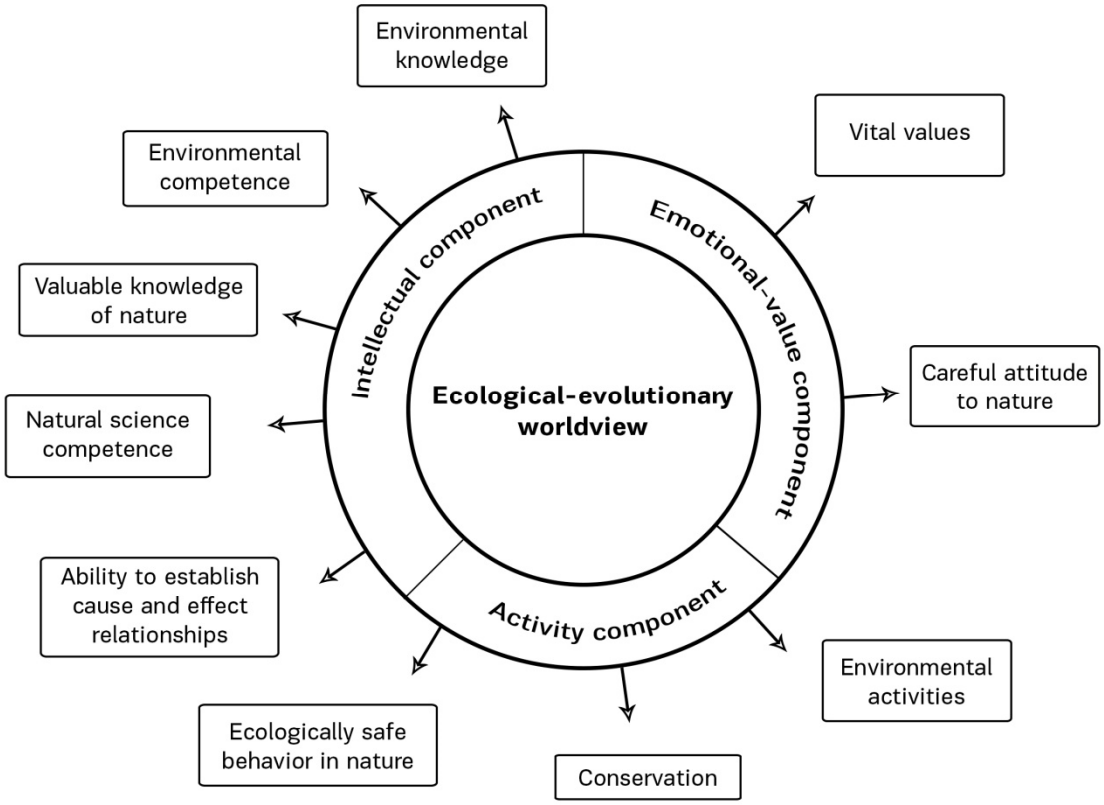

Fig. 1. The components of ecological-evolutionary worldview.

The emotional-value worldview component includes the person's vital values built on the basis of available knowledge, views and beliefs provided by the intellectual component. At that special attention is paid to the development of the person's sense of responsibility for the outside world, their environment and themselves, since responsibility plays the crucial role in natural and social environment rational transformation. The maturity of the EEW emotional-value component is manifested in the person's ability to perceive and understand the integrity of nature, to empathize with all living things, in the self-actualization need, in actual observation of the environmental laws, in resistance to the living environment integrity destruction, in motivation to study, in the desire and ability to keep a healthy lifestyle.

The activity EEW component provides for the person's inclusion in the sphere of interaction with nature, their activity in accordance with the level of knowledge and values available. The mature activity component results in the person's ability to act on the environmental basis with the purpose of preventing damage to the environment and nature. At that we consider activity as a form of active and simultaneously value-based attitude to the world, nature – the way of a human behavior in the biosphere.

In the context of our study we understand by the environmental activities not only educational activities aimed at the knowledge and skills system mastering, the formation of their environmental and scientific competencies together with the subject competencies system, but also the development of positive social and cultural motives of ecologically sound ethical behavior, deliberate activity promoting harmonization and optimization of relations between human and nature, developing ecological and cognitive interests. During ecological activity a person does not only adapt to the natural environment, but also adapts nature to themself, transforms it according to their needs. As a result, the person creates a socio-natural environment where in the course of environmental activities they change natural interrelations into social and cultural ones. At that the person is simultaneously the subject and the object of the environmental activity, the values whereof are their environmental needs.

Environmental activity as the activity EEW component is determined by the following imperatives: an

environmentally sound labor management aimed at relations harmonization in the "human – society – nature" system; activation of environmental, resource-conserving activities; cultural environmental activities.

The EEW presence in person and its result - environmental consciousness – form a new type of person whom we call an ecoperson.

An ecoperson is a type of person coordinating all their life activity with the laws of the biosphere evolution into noosphere, realizing the objectivity and irreversibility of this process; whose environmental and spiritual needs prevail over the material ones [4].

Modern society should form an ecoperson characterized by ecological education and consciousness implying an attitude towards the world as towards themselves, avoiding passive existence for active participation in the transformation of the biosphere into its sphere of reason – the noosphere. Since the modern environmental problems are not large and small Chornobyls, but deliberate consciousness destruction, humanity should move to a qualitatively new living standard – ecological consciousness, which will become the key to its survival.

Opposed to the ecoperson is the type of "homo civition". That is according to S. An [5] who characterizes the homo civition as a person who has lost their inner spirituality, often indifferent, apathetic, aggressive and angry.

"Homo civition, – S. An wrote, – is a person unpredictable in social activity, capable of unmotivated destructive (disruptive) actions, with destructive actions mindset only" [5]. Homo civition's consciousness contains elements of chaos, instability, randomness and disorganization, and the actions of this type of person is characterized by a significant weakening of leadership skills, increasing behavior deviations and so on.

We believe that humanity has only one way to the future – the formation of worldview, culture and mentality relevant to the modern era through the establishment and implementation of the idea of ecocentrism. The ecological and evolutionary worldview should become this worldview.

The implementation of ecological-evolutionary approach ideas in the content of scientific education is performed through an innovative technology of natural sciences (biology, geography, chemistry and physics) teaching.

The purpose of the pedagogical experiment was to organize, conduct and analyze the results of the implementation of natural sciences teaching technology based on the ecological-evolutionary approach principles and to check the ecological-evolutionary worldview formation in the 9th grade pupils of general educational institutions.

In order to objectively evaluate the academic performance in biology of the pupils who have studied under the experiment (according to the innovative teaching technology based on the principles of ecocentrism idea implementation) a criteria system, their rates and levels of pupils' performance have been developed. Performance is understood to be the rate of pupils' mastery of empirical and theoretical knowledge (scientific concepts, facts, laws, theories, patterns), as well as of skills.

The following criteria for the pupils' academic performance evaluation in natural science subjects on the basis of ecological-evolutionary approach were determined: cognitive, activity-creative, personal-significant, or reflective, motivational-behavioral. According to the stated criteria four integrated levels of pupils' performance were separated: elementary, intermediate, sufficient, high.

For the purpose of revealing the ecological-evolutionary worldview formation in the mind of the 9th grade pupils and obtaining the qualitative and quantitative indicators of this process effectiveness the formative stage of pedagogical experiment was conducted.

The results of the pedagogical experiment suggested that the implementation of biology teaching technology on the basis of ecological-evolutionary approach to the 9th grade pupils (identified as the experimental in the study) contributed to a significant increase in the ecological and evolutionary worldview formation at high and sufficient levels according to all the criteria (cognitive, activity-creative, personal-significant and motivational-behavioral) and decrease in the number of pupils with low and intermediate levels which proves the effectiveness of the ecological-evolutionary approach implementation in the natural subjects teaching (Fig. 2).

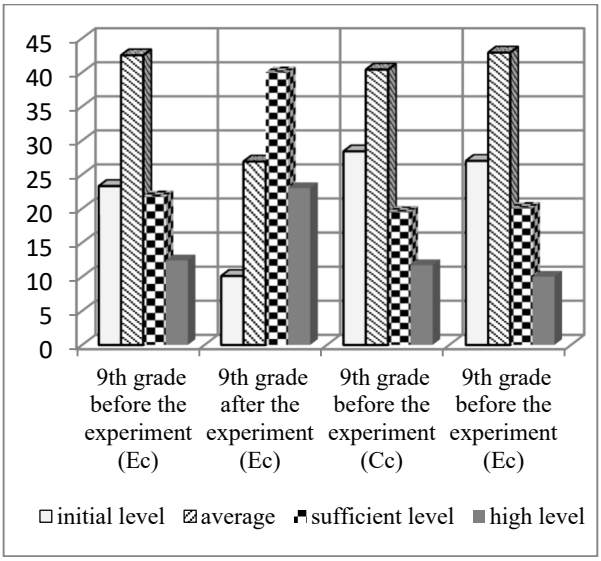

Fig. 2. The dynamics pattern of EEW formation levels of the 9th grade pupils in the experimental (Ec) and control (Cc) groups by the personal-significant criterion before and after the experiment.

The effectiveness of environmental studies subjects/disciplines teaching technology based on ecological-evolutionary approach was estimated during a pedagogical experiment in general comprehensive schools conducted on biology classes.

During the pedagogical experiment the subject student groups of 9th grade (Exp) pupils teaching was conducted following the education technology based on ecological-evolutionary approach, based upon using original biology teaching methods with the ecological-evolutionary approach and an educational methodological provision

system (biology textbooks, accordant guides for pupils and a methodological guide for teachers). In the control groups of 9th grade (Cc) the pupils studied according the classic education system following biology textbooks and guides that were based on ecological-evolutionary approach.

The achieved pedagogical experiment data analysis proves that students being taught biology on the basis of ecologic-evolutionary approach facilitated a major decrease in their quantity, with the lower (from 19,4 % to 4,9 % according to the cognitive criteria, from 18,2 % to 6,6 % according to the activity and creativity criteria, from 16,2 % to 7,4 % according to personal importance criteria and from 17,7 % to 6,4 % according to motivation and creativity criteria) and middle (from 53,8 % to 17,4 % according to the cognitive criteria, from 45,9 % to 19,8 % according to the activity and creativity criteria, from 43,4 % to 22,3 according to personal importance criteria and from 17,8 % to 6,2 % according to motivation and creativity criteria) levels of education, at the same time the number of students increase on satisfactory (from 24,0 % to 49,7 % according to the cognitive criteria, from 23,7 % to 47,2 % according to the activity and creativity criteria, from 25,8 % to 44,9 % according to personal importance criteria and from 26,0 % to 40,7 % according to motivation and creativity criteria) and on higher (from 16,0 % to 25,9 % according to the cognitive criteria, from 12,1 % to 26,6 % according to the activity and creativity criteria, from 14,5 % to 25,5 % according to personal importance criteria and from15,8 % to 33,2 % according to motivation and creativity criteria) levels (the data compared was gathered before and after the experiment). The changes in education level among the students in control groups are hardly noticeable.

Quantitative and qualitative analysis of the pedagogical experiment results proves that the teaching technology based on ecological-evolutionary approach is effective along with the concepts and didactic principles represented within it, which confirms the research original hypothesis. The research has proven that the ecological-evolutionary approach application in teaching 9th graders biology substantially influences the quality of the pupil's knowledge: the formation of complex ideas about wild-life, biological knowledge capacity, ecological competence and ecological-evolutionary ideology.

5 Conclusions

Comparing the levels of ecological-evolutionary worldview formation of the 9th grade pupils in control and experimental classes who were taught according to ecological-evolutionary approach natural sciences teaching technology we found out that all the criteria at sufficient and high performance levels are much higher for the pupils of experimental classes than for the pupils of control classes. The difference in the number of 9th grade pupils of control and experimental classes with elementary and intermediate performance levels according to the same criteria was revealed.

The results of the pedagogical experiment suggested that the implementation of biology teaching technology on the basis of ecological-evolutionary approach contributed to a significant increase in the ecological and evolutionary worldview formation at high and sufficient levels according to all the criteria (cognitive, activity-creative, personal-significant and motivational-behavioral) and decrease in the number of pupils with low and intermediate levels which proves the effectiveness of the ecological-evolutionary approach technology in the natural subjects teaching.

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Issues of shaping the students' professional and terminological competence in science area of expertise in the sustainable development era

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Abstract. The paper deals with the problem of future biology teachers' vocational preparation process and shaping in them of those capacities that contribute to the conservation and enhancement of our planet's biodiversity as a reflection of the leading sustainable development goals of society. Such personality traits are viewed through the prism of forming the future biology teachers' professional and terminological competence. The main aspects and categories that characterize the professional and terminological competence of future biology teachers, including terminology, nomenclature, term, nomen and term element, have been explained. The criteria and stages of shaping the future biology teachers' professional and terminological competence during the vocational training process have been fixed. Methods, techniques, technologies, guiding principles and forms of staged work on the forming of an active terminological dictionary of students have been described and specified. The content of the distant special course "Latin. Botanical Terminology", which provides training for future teachers to study the professional subjects and to understand of international scientific terminology, has been presented. It is concluded that the proper level of formation of the future biology teachers' professional and terminological competence will eventually ensure the qualitative preparation of pupils for life in a sustainable development era.

1 Introduction

Ukraine, among other countries, has pledged to achieve the 17 Sustainable Development Goals by 2030 to fight poverty, hunger and climate change and ensure well-being and prosperity for all segments of the population. In 2015, the General Assembly of the United Nations formulated the following Sustainable Development Goals, namely:

The Goals 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

The Goals 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

In this connection, biodiversity conservation is one of the most important components of Ukraine's state environmental policy. The biodiversity creates a safe environment for human life and health providing the population with food, medicine and raw materials for industry. It also supports the functioning of ecosystems including the circulation and purification of natural waters, soil conservation and climate stability. Ukraine, accounting for only 6% of Europe's total area, owns 35% its biodiversity [1].

The biodiversity conservation is one of the key components of a sustainable development strategy society and countries' environmental policy of the world and the EU. Thus, it's necessary to create a clear and effective system of formation of population's ecological culture and to prepare for this aim the qualified specialists in the biology area of expertise [2].

Today, in the environmental education and upbringing scope, the problem of the mismatch of young people's environmental knowledge to their behavior in nature is current importance. According to the Biological Diversity Conservation Concept of Ukraine, "... environmental knowledge should become a mandatory qualification requirement for all officials whose activities are related to the use of natural resources or to affect the environment" [3]. That is why the preparation of the future science teacher, who possesses the conceptual apparatus, terminology and nomenclature of living organisms, becomes relevant.

At the same time, it should be noted that modern higher education is oriented at finding methodical ways of organizing the educational process and directed at training a competent specialist that ready for further professional and communication activities. The earnest of success of specialists in the modern labor market and to ensure their competitiveness in the sustainable development era is knowledge of professional terminology. The well-formed

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professional and terminological competence of future biology teachers reflects their ability to understand professional phenomena and concepts, as well as the existing level of their professional language culture.

The purpose of the study is to identify the nature and role of terminological and nomenclature units in the system of future biology teachers' subject knowledge, moreover to develop a procedure for the formation of professional and terminological competence of future biology teachers who are able to perform the main professional functions in the sustainable development era.

2 Materials and methods

The presented study broadly analyzes the scientific works concerning the problems of shaping the future specialists' terminological competence (Halyna P. Bondarenko, Tetiana O. Butenko [4], Oksana Ye. Hrydzhuk [5], Tetiana A. Denyshchych, Emiliia I. Ohar, Larysa L. Rytikova, Tetiana V. Symonenko, Tetiana V. Stasiuk and others), as well as of their professional and terminological competence (Liliia V. Baranovska [6], Valentyna D. Borshchovetska, Nataliia S. Borodina, Lesia V. Viktorova, Iryna V. Vlasiuk, Volodymyr O. Domin [7] and others). Source analysis shows the most authors investigate the role and correlation between professional nomenclature and terminology in the humanities study context, and mainly during preparation of the students of language specialties.

At the same time the terminological system and professional and terminological competence in science area of expertise that formed in the students are essential for the sustainable development of society, in particular in the biodiversity conservation context. Tetiana L. Andriienko-Maliuk, Anna Y. Aleksandrova, Oksana O. Veklych [8], Olena V. Vrublevska, Lidiia S. Hryniv [9], Yurii M. Hryshchenko, Petro I. Haman, Leonid H. Melnyk, Ihor M. Syniakevych [10], Anatolii Ya. Sokhnych and others emphasize on this fact in their works.

It should take into account, the problem of biodiversity conservation is widely covered in the researches of domestic and foreign scientists, in particular Tetiana L. Andriienko-Maliuk, Anna Y. Aleksandrova, Oksana O. Veklych [8], Olena V. Vrublevska, Lidiia S. Hryniv [9], Yurii M. Hryshchenko, Petro I. Haman, Leonid H. Melnyk, Ihor M. Syniakevych [10], Anatolii Ya. Sokhnych and others. These works mostly study maintaining the ecological status of ecosystems. Serhii M. Bobylev, Henadii O. Motkin, Oleksandr S. Tulupov [11], Watson N. Dudley, Alexander N. James, Marc Hokungs, Stefano Pagiola and others investigate the economic aspects of biodiversity conservation.

It is known, any term functions in the environment of the nomen corresponding to it. The relation between the concepts "term" and "nomen" is still debatable. For the first time the issues of their delineation were raised in the researches of Hryhorii O. Vynokur and further developed in the works of Arkadii V. Lemov [12], Volodymyr M. Leichyk [13], Oleksandr I. Moiseiev [14], Hustav H. Shpet and others [15]. We assume that mastering the professional terminosystem by students is an interdependent process of studying by them binary nomenclature. For future biologists the professional terms are usually of Greek-Latin origin. Therefore, if biology teachers know the term elements, principles of word formation they can understand and correctly use of terms in professional speech.

Despite the elaboration of the problem of scientific terminology and terminosystem, the issue of the relation between nomenclature and terminology in the forming of the future biology teachers' terminosystem still remain out of the researchers' attention just like ways and means of shaping of the professional and terminological competence during the vocational training process.

Thus, in this paper, on the basis of the primary sources' analysis, through their generalization, concretization and interpolation, the methodology of forming professional and terminological competence in the future biology teachers will be modeled.

3 Theoretical background

Scientific terminology is the highest manifestation of human thought, the main structural element of the refinement and standardization of the language of a particular branch. The "term" is a word or phrase that means a clearly defined special concept of any field of science, technology, art, public life, etc. [16, p. 76]. Terms are used in the process of knowing and mastering scientific and professional objects and relations between them [17, p. 4-10].

While the analysis of terms by students, the priority is the structural-and-cognitive aspect, which consists in mastering by them the terminoelements. In fact, because biological terminology has Latin roots it is necessary to study semantics and etymology of the terminological elements of Greek-Latin origin. Evidently that on the basis of a capacious system of terminoelements, it is possible to form an individual active terminological dictionary of a future specialists, that is the core of their professional and terminological competence.

In our previous researches we defined the professional and terminological competence as a formed specialists' ability to correctly and appropriately use professional terms in their professional activity; as well as that is the set of acquired skills of oral and written language and the experience gained during the study of professional oriented subjects [18].

Among the criteria for the formation of future specialists' professional and terminological competence are the following [19]:

– the volume of professional terminology knowledge and the quality of professional speaking;

– the motivation in studying of professional terminology, the awareness of importance and necessity its using in the future profession;

– the efficiency in the utilize of professional terminology, the ability to use it while doing of own duties;

– the vocational approach in choosing language tools to explain processes and natural phenomena;

– the skills to use professional terminology in the process of establishing communication relations, and awareness of the readiness to utilize it guided by personal traits [20, p. 17].

The forming of future biology teachers' professional and terminological competence is carried out in stages. The purpose and objectives of each of the steps are put forward with the focus on the development of a stable professional terminosystem via a students' active individual terminological thesaurus.

The *reproductive (preparatory) stage* (I course) is directly related to the adaptation of students to teaching at a pedagogical university, the development of scientific and cognitive interests and ideas about the structure of terms, etymology and semantics of basic terminoelements. The reproductive stage includes a diagnostic module, a module of general theoretical and scientific training of students, a module of methodological training, during which lay the foundations of mastering the scientific terminology by future teachers.

At the *practical-methodological stage (II-III courses)*, in the conditions of interaction instructional work with the course of field practices, students practically master and consolidate components of professional and terminological competence.

Activity-creative (final) stage (IV course) includes production practice, performance of qualification works. At this stage, the results of students' educational activities integrate into the content-information, operational-activity and personal levels, and the content of professional and terminological competence is made adjust and deepen.

Next, we look at the main aspects and categories that characterize the professional and terminological competence of future biology teachers and the main directions and tools its shaping.

4 Didactical support of shaping the students' professional and terminological competence

4.1 Developing the content of the terminosystem and nomenclature key concepts

Let's consider the relation between nomenclature and terminology. A terminosystem is a system of science terms containing a plurality of interrelated elements that constitute a stable unity. Nomenclature is a set of special terms-and-names used in this scientific field; the names of typical objects of this science (as opposed to terminology that include the designation of abstract concepts and categories) [21]. Unlike the terms, referring to certain abstract concepts and categories, the nomenclature is a certain inventory system of the science.

In particular, Grigoriy O. Vinokur points out following "as to nomenclature, this term, in contrast to terminology, should be understood as a system of absolutely abstract and conventional symbols, the sole purpose of which is to give, from a practical viewpoint, the most handy means of marking objects or things without direct connection with the need using of theoretical thinking". The terminosystem unit is the term and the nomenclature unit is the nomen [15].

In the heart of the distinction between the concepts "term" and "nomen" is taken their specific-and-subject or generalized conceptual relation. According to O. Moiseyev, this fact caused by the difference between "conceptual" and "substantive" terminology, that is, designations that more clearly reflect one's own conceptual orientation (i.e. the terms) or subject orientation (the nomens) [15].

There are three types of nominative units [20], such as: 1) nomenclature words, which mainly express single concepts and contain information about one object of reality and make subject relations; 2) industrial engineering terms expressing the general concepts and reflect a whole class of homogeneous objects and actualize the subject interrelationship; 3) scientific terms expressing general concepts and make conceptual relations (see Fig. 1). However, such a division of nominative units is rather conditional.

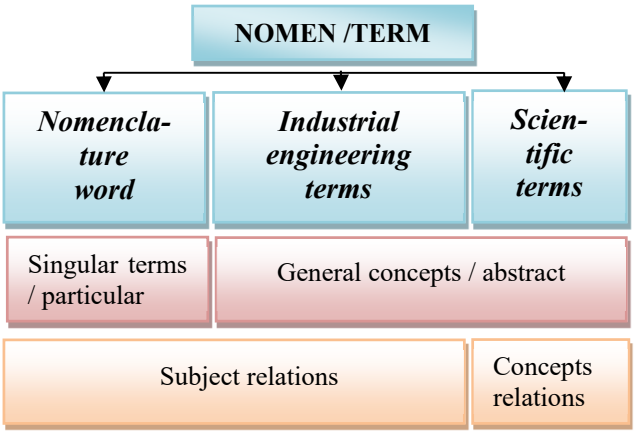

Fig. 1. Correlation between terms and nomens.

Thus, terminology considers nomenclature units as special types of terms that relate to individual concepts and actualize subject relations [22]. The peculiarity of the term, that distinguishes it from a word or a nomen, is its inseparable connection with a certain concept. What's more, a term carries out two functions: it names the subject and reflects the concept's content essential signs.

There are also differences in terminosystem and nomenclature one. The terms combine into a complex branching system (network) with hierarchical relations, and the nomens unite in rows that can "grow into" a rather simplified system. The nomenclature is accordingly defined as a component of the terminosystem or similar to it, but somewhat simplified.

The biological nomenclature is represented by nomens that correspond to the levels of the conditional division of the organic world into taxa such as species and super-species. Species names can also be called The Binomen [23] because they consist of generic and species organism names, as for example: Couch Grass – *Elytrigia repens L.* The nomenclature ensures the uniqueness of the nomen that is the basis of biological research including study of biodiversity [24].

Among the biological nomens it can be single out phytonomens, zoonomens, myconomens, which are respectively a nomenclature of plant, animal organisms and fungi. There are quite a few terms in the literature that are used to refer to vegetal and animal world. Given that the nomenclature includes nomens, it is more appropriate to utilize phyto-, zoo-, myconomens in the professional terminosystem and to use a term, as for instance, "phytonomen" rather than "phytonym".

Apparently nomenclature is part of biological terminology, but so to speak specific. The term elements are common to terminology and nomenclature (see Fig. 2).

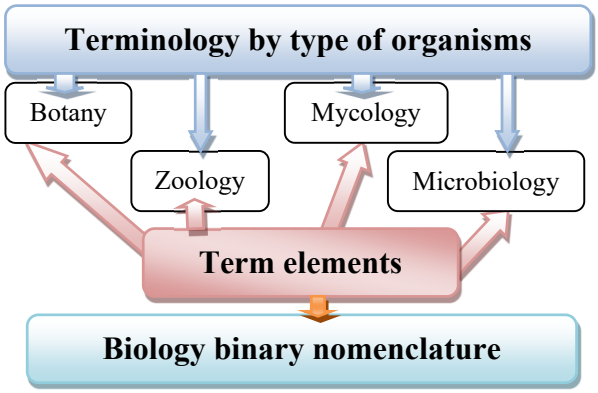

Fig. 2. Biology terminology and nomenclature in the system of professional knowledge.

In view of the above, it becomes clear that the future biology teachers should be able to properly speak the profession language, understand and use binary nomenclature in practice, have a high level of professional and terminological competence. This will, in the end, contribute to the conservation and enhancement of biodiversity and the achievement of sustainable development goals of society.

4.2 Methodical support of shaping of students' professional and terminological competence

The terminology mastering process has own peculiarities and complexities. In the first stages of studying the professional oriented subjects, students accumulate set of terms, which are often unsystematic and disparate. Practical experience shows it is only through purposeful work on the concepts' content that students can remember the terms profoundly. New terms are being introduced during the learning of concepts in course of teaching the study material, discussion or explanation, demonstration of nature objects or images, laboratory work, practical classes, excursions, and whatever. It is important for the same terms to be used in different learning situations, to be manifested in the direct observation of natural (or virtual) living nature objects [25, p.186-187].

Ivan. V. Moroz distinguishes the following methods and techniques of terminological work:

– Drawing of anatomical and morphological texture and structural units.

– Putting in a term during the explanation, recording with the following verbal or written interpretation, creating the special terminological dictionaries.

– Repeating articulation of term to train correct pronunciation.

– Determining the term's etymology and its translation into the native language.

– Clarifying the semantics and content of the term.

– Using of analytical and synthetic techniques that allow to disclosure etymology of concepts forming the term.

– The comparison method realization.

– Filling of parametric and resumptive tables, drawing up the word-logical schemes

– Making correlation of term and concept through techniques of underlining, selection, and grouping [25, p. 184].

Natalia A. Menchynska [26] believes there are two important stages in the terminology mastering process; these are macrogenesis and microgenesis. Throughout definition of concepts (in microgenesis) students carry out a logical operation, the essence of which is to disclose the meaning of the concept. During macrogenesis the concept enrich by theoretical notions, facts, methods and language of science; its scope and content expand in the implementation of interdisciplinary relations process. Therefore, mastery of scientific terminology depends on the level of formedness the students' skills to classify, summarize, find relationships, use facts as arguments in the course of proof, build and decipher models, do experiments, solve exploratory tasks.

Let's stay on a complex of *didactic methods and means* aimed at shaping terms and nomens which actually actualize during both the classroom work and independent work of future biology teachers. The didactic support of shaping of future biology teachers' professional and terminological competence is summarized in the scheme of Fig. 3.

A significant fundamental of shaping of the professional and terminological competence is students' *active individual terminological thesaurus* which creates on the base of mastering by the vocational terminology system. It should take into account that the terms' systematization into the terminosystem requires a creative and active approach, and implements with use of well-known classroom forms of work as well as extracurricular and distant kind ones.

During independent work the conditions for thorough mastering of professional terminology by students are created. *Independent work with a textbook or vocabulary* allows systematize terminological knowledge and consists in the compilation of a glossary on a specific topic or module, as well as an individual terminological dictionary in a particular subject. *Work with microproducts, models and dummies* enables a visualization of the study material. Such independent work can be done both in real and virtual environment (digital photos of microscopic tissues' structure, 3-D digital models of structure of organs and systems, etc.). The advantages of virtual models over plane graphical images are their volume, expanding their scope to objects where the study of the topography of parts, their relative distribution and subordination are important.

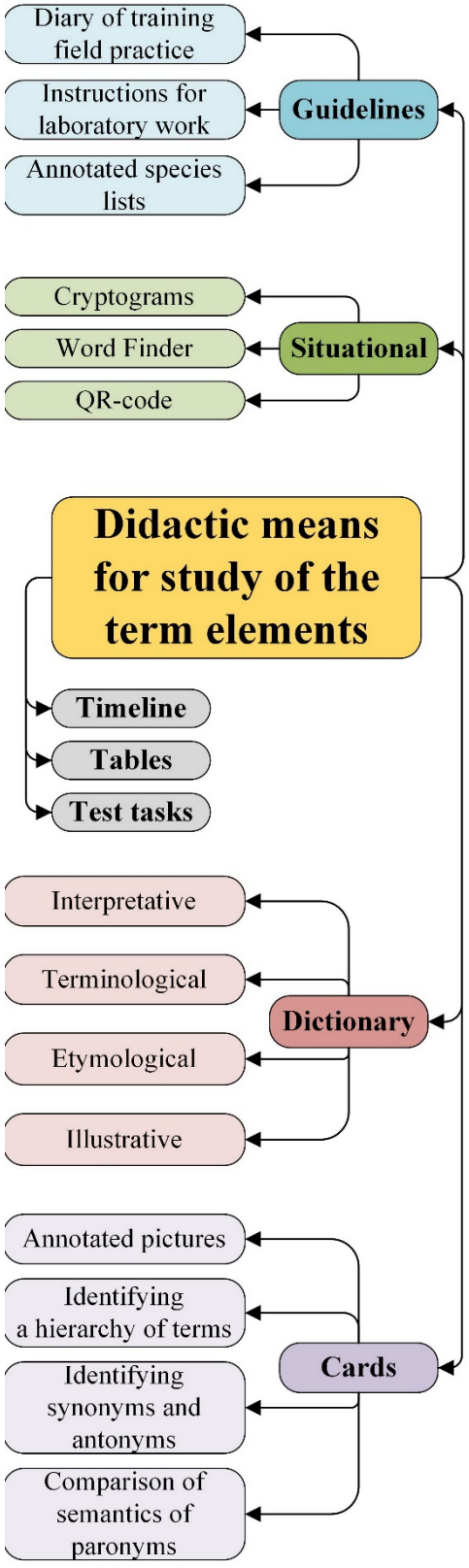

Fig. 3. The didactic means of shaping of future biology teachers' professional and terminological competence.

Terminological work with natural objects ensures the formation of correct ideas about the laws of the functioning of living organisms and nature phenomena. The biological terminology elaboration occurs during work with herbariums, various biological collections (seeds, fruits, skeletons, etc.), including virtual and digitized ones [27].

Evidently the effectiveness of shaping professional and terminological competence is largely determined by the students' motivation for perception and processing, active search and systematization, self-development and creative approach in mastering professional terminology. The realization of this purpose is facilitated by the introduction of *innovative, interactive and imitation-game forms of learning*, based on the principles of clearness, visualization, dialogue, gamification, individual and competent approaches. Advantages of use interactive innovative methods are increasing of students' motivation to study professional terminology, compliance with the individual rate of professional information processing, identification of specificity and semantic-and-etymological relations between the term elements, simplification of semantic and etymological analysis of terms and specificity of word formation, improving the skills to work with reference literature by specialty.

Among the various tools of creative study of terminology there is the *looping technology* that assumes a repeated return to what has been learned in order to consolidate the already tried and tested terminology [28]. In course of the laboratory studies and practical preparation it is need to take advantages the *technologies modeling of professional orientated situations* which ensure the improvement of future the specialists' professional speech and communicative skills.

Advisably to usage *mobile learning technologies* and actively implement mobile apps to identify plants, to study Latin, chemical structure and properties of substances, anatomy and whatever, during field practice and independent work of future biology teachers. These apps can significantly simplify the completion of individual search tasks by students for work off the professional terminology [29].

In course of lectures and laboratory-and-practical studies can be effective such *interactive methods* as the method of word-and-clouds (word-tags, word clouds), mind maps (mental maps), semantic-and-etymological analysis of the term and its word-formation, synonymically-and-antonymically-and-paronymic method (which eliminates in future confusion in identification of the various terms) and others.

It is the *simulation method* that can ensure efficiency and effectiveness of terminological work. Modeling refers to the process of creating models that mimic biological objects or processes. The result can be represented in material or informational form, as for instance in the form of dummy, text, spreadsheet, graphic, computer model, etc. The main functions of the modeling method in the shaping of students' professional and terminological competence are heuristic and generalizing ones.

In order to gain a clear understanding and systematization of terms on a particular topic, it is advisable to use *schematic-and-sign visualization*, which allows attract students' eidetic and visual memory. Mastering a terminosystem on a specific topic or module with help of such type visualization enables reveal the structure of the concept being studied and the essential connections between the components [30]. As a practice

shows, characterizing the terms and the relations between them can be efficiently with use the following means and tools:

– Intelligence Cards (MindMap).

– Venn diagrams – techniques of graphical presentation of information during comparing two or more concepts or ideas that are simultaneously both similar and different.

– Schemagraphics – a step-by-step investigation of the concept in a diagram form.

– Concept tables comparing terms by the same criteria or attributes.

– "T-diagrams" – a way of displaying and organizing the results of the term's analysis taking into account its properties.

– "Bloom's Chamomile" (chamomile of questions) – a graphic representation of phased study of a certain term.

– The schemes with brackets for the grading of the term on a much larger number of grounds (see Fig. 4).

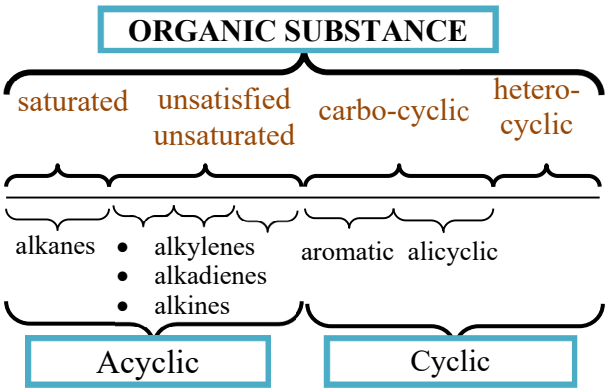

Fig. 4. The schemes with brackets.

– The tree of graphs or trees of concept.

– Structural diagrams with rectangular blocks, rhombuses and arrows denoting parts of phenomena and possibility of alternative transitions, and connections of parts.

– The infographics – schematic depictions of the concepts' system and connections between them via graphical means.

– The structural-and-logical schemes of topics or sections [31; 32].

The application of these tools is the most important moment for situations of perception, design and creative transformation of professional terms by future biology teachers. In this case, the introduction and assimilation of procedures for schematization and operating on with schemes is a key in shaping of the students' professional and terminological competence [33]. The only fundamental drawback of the terminosystem's schematic-and-sign visualization tools is the considerable complexity in their production and working off.

It should be emphasized that with the accumulation of the scientific terminology by future biology teachers would do well to conduct the timely control of learned terms. Didactic cards that combine several techniques of terminological work, as well as biological or terminological dictations, can be used to test knowledge.

Therefore, it can be convinced that profound mastery of concepts is possible only if students master the specialty language in a timely and systematic manner, learn special terms during purposefully organized activity. Thus, the activity approach provides for the circumstances in which a student can independently identify the common and particular, can classify, conduct and organize observations of the studied phenomena and objects [34]. As a result of the application of a number of didactic means, purposeful and gradual shaping of future biology teachers' professional and terminological competence is possible.

4.3 Overview the content of the distance course "Latin. Botanical Terminology"

The distant special course "Latin. Botanical terminology" is intended for students of specialty 014 Secondary education (Biology and human health) of Kryvyi Rih State Pedagogical University [35]. This course aims to increase students' awareness in biological terminology, contributes understanding of the relations between Latin and Ukrainian, and facilitates the terminosystem's assimilation (it shown in Fig. 5).

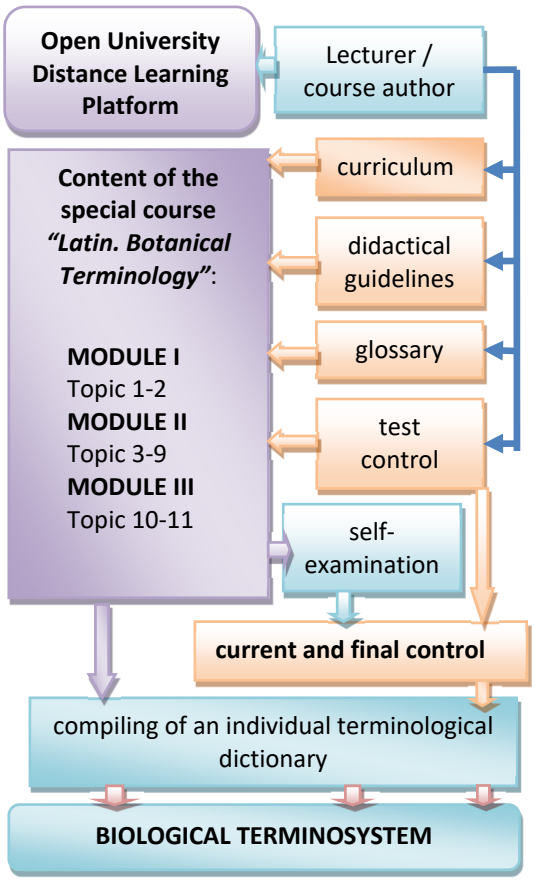

Fig. 5. The course of "Latin. Botanical Terminology" structure.

One of the main objectives of the course at the Sciences Faculty is to prepare the future teachers, based on knowledge of Latin, to perceive special courses (the professional cycle subjects) and to understand of international scientific terminology. As experience has

shown, familiarity with Latin develops logical thinking, enhances linguistic culture and promotes widening the students' general outlook.

During the formation of the special course's content we proceeded from the assumption that the teacher's professional activity requires not only professional skill but also a broad general subject knowledge (professional competence), literate oral and written speech. The modern high school aims at forming not only the skills of intellectual work, but the creative abilities of the future specialist. The ability to use the acquired knowledge creatively is a social value because it helps the specialist to perform social and professional functions, quickly adapt to new economic conditions, promotes a flexible transition from one activity to another. In this viewpoint the professional and terminological competence is determined by the literacy of the use of subject professional terminology in professional activity. These qualities are very important both for the future biology teacher and for any person in the sustainable development era.

Let's consider the main content of the special course *"Latin. Botanical Terminology".*

Module I. History of the biological terminology and nomenclature formation.

Topic 1. The concepts of "scientific term" and "terminoelement".

Topic 2. Binary Nomenclature: purpose and history of formation.

Module II. Principles of the phytonomens construction.

Topic 3. The informative content of the Latin names of living organisms.

Topic 4. Methods of formation of the Latin species epithets.

Topic 5. Botanical Eponyms: Classification and Meaning.

Topic 6. The etymology of plant names.

Topic 7. Widespread plants species names. Ukrainian and Latin phytonomens.

Topic 8. Latin names of plant communities.

Topic 9. Sense of the main term elements as components of word-building.

Module III. Binary Scientific Nomenclature and International Nomenclature Code.

Topic 10. International Code of Scientific Nomenclature:

ICBN (International Botanical Nomenclature Code),

ICNCP (International Crop Nomenclature Code),

ICZN (International Zoological Nomenclature Code),

ICNB (International Bacterial Nomenclature Code).

Topic 11. Rules and principles of the international binary nomenclature.

Reasoning from the specificity of the study of Latin as the basis of biological terminology, during the special course, the focus attention is to the terminological sense of words, the investigation of Greek-Latin terminosistem, as well as the study of etymology and semantics of biological concepts. Among the varieties of tasks for the shaping of students' professional and terminological competence we used such as: the task of mastering terminoelements and basic phytonomenes, ones of compiling comparative and summarizing tables, exercises on the correct pronunciation, stress, the definition of terminological bases as well as of prefixes, suffixes, and flections of words; creating degrees of comparison of adjectives, numeral terminoelements, etc.

In the end, it contributes to the shaping and development of the future biology teachers' professional and terminological competence.

4.4 Use of the National Biodiversity Information Network in terminological work with students

As noted above, one of the goals of a sustainable development society is to conserve our planet's biodiversity. According to the Biological Diversity Conservation Concept of Ukraine for 2005-2025 [36], it is envisaged for the current period to ensure the implementation series of measures. This means the reproduction of plant and animal species populations, their natural communities and ecosystems, improvement of the infrastructure which necessary for the Program implementation, as well as its goals adjustment and do control over their decision. Successful implementation of these tasks requires continuous monitoring of species diversity provided by the Ukrainian Biodiversity Information Network – *UkrBIN* [37].

UkrBIN is a pilot project, the only platform in Ukraine for free access to biodiversity accumulation and exchange. Anyone can join to give a leg up the nationwide database on biodiversity, distribution and abundance of plant and animal species in Ukraine and the world, at the same time to help preserve the natural potential of our planet.

It should take into account the data collected under the *UkrBIN* project are part of the largest international biodiversity data registers of the Catalog of Life and the Global Biodiversity Information Facility (GBIF) [37]. *UkrBIN* has a user-friendly interface, an open database that shows the presence and abundance of species using data from downloaded taxa lists.

The main features of the *UkrBIN* database that can be used in the educational process of preparing a future biology teacher are following:

– digitalization of own or common observations (uploading photos and descriptions);

– tracking own annotated watch list;

– searching a photo to identify plants or animals;

– finding out the trophic connections;

– studying of dynamic maps and graphs;

– viewing the phonograms (annual phonograms, frequency of occurrence data and species abundance, and whatever);

– browsing by region statistics and annotated lists (by country, region or area) with use queries and filters;

– viewing by map of the species, genera and families distribution;

– using rapid field determinants for the study of flora and fauna, designed for teachers, students, ecologists, nature conservationists and amateur naturalists.

The participation of future biology teachers in expanding the *UkrBIN* database increases their motivation

in the development of professional subjects and field practice, introduces them to the problems of biodiversity conservation for the goals of society's sustainable development. Not only this resource allows viewing the database, but also adding one's own observations, commenting, participating in the forum. It helps to develop communication skills and expand the individual active terminological dictionary of a future specialist.

5 Conclusions

The problem of conservation and increase of the biodiversity of our planet deserves special attention among the leading goals of the sustainable development of society. This difficult issue can be solved by way of the preparation of qualified biology teachers who have master a high level of terminosystem and binary nomenclature of modern science.

Professional and terminological competence is defined as the formed ability of specialists to competently and expediently use professional terms in their professional activity. The main aspects and categories that characterize the professional and terminological competence of future biology teachers are the terminology and nomenclature and, accordingly, the term and nomen. The terminosystem unit is a term denoting a certain abstract concept and categories. The unit of nomenclature is nomen that is special terms-name meaning single, and specific concepts. The nomenclature is seen as a component of the terminosystem, or as an intermediate link between terms and their own words. The biological nomenclature is represented by numbers (species binomials) that correspond to the extent of the conditional division of the organic world into taxa. The nomenclature ensures the uniqueness of the nominees in biological research. We believe that nomenclature is a specific part of biological terminology. The term elements are common to terminology and nomenclature.

An essential feature of Latin nomens, approved by the relevant codes of nomenclature, is that they have international recognition, facilitate communication between scholars and promote the science development. The distant special course "Latin. Botanical terminology" has intended for study of the biological terminology and shaping the future biology teachers' professional and terminological competence.

Understanding the essence and structure of professional and terminological competence is the initial stage for design a methodology for its formation during the future biology teachers' vocational training process. Among the didactic means for the shaping of professional and terminological competence are the following: methods and techniques of terminological work, active individual terminological dictionary, independent work on a specialty, innovative, interactive and imitation-game forms of learning, based on the principles of clearness, visualization, dialogue, gamification, individual and competent approaches, as well as a looping technology, modeling of professional orientated situations, mobile learning technologies, interactive and simulation methods, schematic-and-sign visualization.

A significant impact on the formation of students' professional and terminological competence is provided by work with the Ukrainian Biodiversity Information Network – UkrBIN. This resource makes it possible to observe and record, distribute among naturalists, discuss, track and replenish data on the biodiversity of our planet

On the basis of mastering the capacitive system of term elements it is possible to form an individual active terminological dictionary of a future specialist. This, in turn, will provide high-quality preparation of students for life in a sustainable development era.

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Problematic issues of geographical education in Kazakhstan

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Abstract. Geographical education in the post-Soviet countries after independence is oriented to the Western model of teaching disciplines. What positive and negative results have been obtained to date are discussed in this article. In the last four years, the educational process in schools has been focused on an updated program. As a result, an interesting question arises: how do we teach students? And this question, what subject we are studying, is moved to the background. The mass transfer of school subjects to a new model of education led to disintegration. In this article, the authors try to analyze the state of geographical education in Kazakhstan, to characterize the process of studying geographical disciplines from the seventh to the eleventh grade. As the authors of the updated textbook, we found many inconsistencies and issues that need to be addressed immediately. There is a model of geographical education, using the material of the updated program to preserve the traditions accumulated over the years of geographical education and upbringing.

1 Introduction

The goal of the modern education system is to give the student the minimum of knowledge and skills that will allow him to start an independent life and are considered an initial step in the educational process and in the formation of a person. A school is a learning environment, and its core is the teacher. A teacher of a new formation must have spiritual, moral, and civic responsibility, characterized by a high level of reflexive, self-fulfilling methodological, research, and other competencies.

Within the framework of the results-based education model and the new management paradigm, there is a need for training aimed at developing the professional culture of teachers in order to master certain concepts and norms, and effective learning technologies.

Therefore, today the country's education system faces the task of providing the educational process with new content based on fresh ideas.

In the process of improving the quality of education and moving to a result-oriented model, teachers must have a highly informative and communicative culture with a high level of activity. To improve the quality of education in Kazakhstan, the State program of education development for 2011–2020 has been developed. The law on the status of a teacher was adopted [1]. In this regard, reforms and policies, changes and innovations in the country's education system can become the basis for each pedagogical community to think, reflect on the past and the present. Work with new ideas and face the problems of the updated program.

The main goal in the traditional education system is to ensure that it is result-oriented, based on the competence of the individual, to prepare the most qualified person and enter the world educational space.

The Concept of 12-year education in the Republic of Kazakhstan states that the main task of forming professional and personal competence of teachers is to possess the following competencies:

- special competence is the ability to predict your professional development;
- social competence is the ability to carry out professional activities;
- educational competence is the ability to use the basics of pedagogical and social psychology [2].

The program that we studied in today looks incomplete, so it needs changes and updates. Some would like to return to the Soviet system of education, in which everything was clear, but this is currently impossible. The main task of the school is not just to give children knowledge, but to teach them to apply their knowledge in practice in everyday life. We need to encourage students to get their own knowledge and search for information using the possibilities of digitalization. That's the point of the updated content.

If we want to teach children how to use their knowledge in everyday life, this should be done using examples of the subjects taught. There are various forms and methods. For example, developing projects, becoming experts and managers, working in groups, using the opportunities of tourist and local history,

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environmental work, etc. Therefore, according to the requirements of the time, we must train and educate the younger generation using new methods. In our opinion, the method works when we have a good, well-thought-out program of disciplines.

2 Results and discussion

According to the developers of the updated content of education program, it is aimed at improving four skills: listening, speaking, reading and writing. The four skills are closely related in the curriculum and are comparable to the "spiral method". The alleged spiral form of learning suggests that re-examining material that will become more complex throughout school education gives a greater advantage in the development of the modern student than traditional forms of learning. This option is questionable. We depart from the principle of what subject we study [3].

The authors suggest that training should be active, conducted in a collaborative environment, and that training should be differentiated in the educational process. Implementations must be implemented on intersubject links. The use of information and communication technologies (ICT) is mandatory. The standard curriculum for the subject "Geography" for grades 7–9 of basic secondary education according to the updated content was approved by the order of the Ministry of education of the Republic of Kazakhstan dated April 3, 2013 No. 115.

According to the standard program, a new-generation curriculum and textbooks have been developed.

The curriculum is developed in accordance with the State compulsory standard of secondary education (primary, basic secondary, General secondary education). The volume of the academic load on the subject "Geography" is:
1) in the 7th grade – 2 hours a week, 68 hours in the school year;
2) in the 8th grade – 2 hours a week, 68 hours in the school year;
3) in the 9th grade – 2 hours a week, 68 hours in the school year.

The content of the subject includes 6 sections:
1) Methods of geographical research;
2) Cartography and geographical databases;
3) Physical geography;
4) Social geography;
5) Economic geography;
6) Country Studies with the basics of political geography.

These sections are studied in grades 7–9. As indicated in the program, the purpose of the textbook "Geography" in high school (grades 10–11) is to create conditions for students to apply geographical knowledge, skills and abilities aimed at solving geo-ecological, geo-economic, social, geopolitical and global problems that arise at all levels of geographical space. For Example: Section 1. Methods of geographical research on the topic-current methods of geographical research, which set such goals:
11.1.1.1 – to apply elements of geographical expertise according to the research topic;
11.1.1.2 – to apply the methods of expert assessments according to the research topic;
11.1.1.3 – to apply modeling methods according to the research topic;
11.1.1.4 – to apply zoning methods according to the research topic.

The volume of the academic load on the subject "Geography" in the natural-mathematical and social-humanitarian areas is:
1) in the 10th grade natural-mathematical direction (NMD) – 4 hours a week, social-humanitarian direction (SHD) – 3 hours a week of the school year;
2) in the 11th grade NMD – 4 hours a week, SHD – 3 hours a week of the school year.

The content of the subject includes 7 sections:
1) Methods of geographical research;
2) Cartography and geoinformatics;
3) Environmental management and geo-ecology;
4) Geo-economics;
5) Geopolitics;
6) Country studies;
7) Global problems of humanity.

After looking at the layout of hours and sections, schoolteachers find it difficult to navigate the learning space. This is a fact. To date, textbooks for the updated program and it can be seen that content a lot of repetition and duplication. The geography of Kazakhstan is spread across sections from grades 7 to 11. There are outstanding topical issues of geography on geo-economics and country studies. There is no industry as tourism at all. The authors of the article wrote a class 11 textbook on the SHD for 102 hours. Therefore, we know enough about the disadvantages and positive aspects of the updated program.

At this time, there is an examination of textbooks of the 11th grade. It was not possible to change or add additional paragraphs to the content because it was impossible to deviate from the approved program [4]. The authors of textbooks published geography textbooks for secondary schools in previous years. The requirements for the program were different, but in a specific example, the goals were met [5, 6, 7].

The updated textbook is compiled in accordance with the requirements of the updated content of education.

The modernization of Kazakhstan's education, accompanied by the transition to the updated content of training, is aimed at improving the quality of training, a person-oriented approach to learning, and increasing motivation when studying specific disciplines. That is why the implementation of these recommendations in the educational process is becoming particularly relevant. Personal-oriented training, various variants of its implementation in the world practice and approaches to training-the essence of differentiation of training in its various manifestations is described in the work of E. S. Polat et al [8].

The modernization of the educational sphere is taking place against the background of deep political and socio-economic transformations in the world and in Kazakhstan's society. Everything that is happening is

connected with the transition to geopolitical and market relations.

The purpose of the subject "Geography" of the 11th grade is the development of functional literacy of schoolchildren, geographical knowledge, skills and abilities aimed at solving geo-ecological, geo-economic, social, geopolitical and global problems [9].

Skills acquired in grades 7-10 become more complex over time and become applied in grade 11.

The main objectives of the subject are:

1) development of geographical and spatial thinking, understanding of global, regional and local approaches, especially in the areas of geo-ecology, geo-economics and geopolitics;
2) creating conditions for the use of modern methods of processing GIS data in the study of country studies and global problems of mankind;
3) using the acquired knowledge and skills in the subject "computer science", implementation of practical work and tasks that are in the textbook;
4) professional orientation of students by performing various activities related to geospatial methods and data.

The training material is designed in such a way as to develop students' scientific, logical, informative speech. The tasks presented in the textbook are mostly practice-oriented in nature and on they are aimed at developing research skills, logical thinking, memory, observation, and individual personality traits.

Teachers will be able to implement results-based learning, organize independent search activities for students, and objectively measure the levels of development of functional literacy of each student on all subjects of the subject, using the structure and evaluation mechanism proposed in the form of a criteria-based evaluation system.

The purpose of this manual is to provide practical assistance to the teacher in the development of thematic planning for geography class based on the updated content of education, plans of lessons, and of guidance in the selection of pedagogical techniques, method, approach, strategy, etc.

The authors hope that this publication can be used for a creative approach to their work by each interested teacher and will allow, if necessary, a flexible approach to the structure of the lesson, to diversify the methods and techniques of teaching, as well as the content of working with students.

The training manual for students offers the following forms of work:

- independent understanding of the main educational and additional material;
- preparation of reports-messages, abstracts, presentations in the PowerPoint program, preparation and presentation of posters, clusters, maps, etc.;
- project, practical, research, creative activities;
- independent, individual and group work.

The content of the training manual is designed to develop logical thinking in students, the ability to compare, analyze, generalize, evaluate, which will undoubtedly lead to the assimilation and consolidation of the acquired knowledge on the subject without mechanical memorization, as well as the education of students responsible attitude to learning and culture of mental labor.

The training manual was developed by practical teachers and scientists who are well aware of the theoretical material and age characteristics of students.

The authors hope that this guide will help geography teachers in their creative and practical work.

Almost all tasks motivate students to independent and research activities.

Structure of the training manual:

- Scientific and methodological foundations of the course "Geography" of the 11th grade (pedagogical strategies, technologies, methods and techniques of training).
- Methodological features of applying the matrix method in geographical research.
- Goal setting in geography lessons.
- Requirements for students' activities.
- Calendar and thematic planning for the subject "Geography" of the 11th grade.
- Examples of short-term lesson planning developments.

The updated content of the course "Geography" of the 11th grade provides a comprehensive, systematic and socially oriented approach to understanding nature, natural phenomena, socio-economic processes and patterns, and integration processes taking place between countries. Studying geography, students should get an idea of the relationship and interaction of society, economy and nature.

The content of the training material is directed:

- to develop the ability to analyze, systematize and argue your answers;
- to create conditions for organizing and conducting research to motivate students to self-development;
- analysis of the political and geopolitical situation, geo-economics of countries and the ability to solve environmental and other problems using materials about the country or area.

The guiding ideas of the textbook's methodological model are the principles:

- visualizations;
- availabilities;
- awareness and activity;
- strength of knowledge;
- scientific character;
- links between theory and practice;
- naturalness;
- educational training;
- developing training [10].

Students master the techniques of *comparison, generalization, abstraction, classification, systematization, analysis, and synthesis* when performing tasks. Special attention should be paid to those teaching methods where it is necessary to prove the truth of the proposed position, to argue theses, to highlight the main idea, to distinguish between essential and secondary features, to draw conclusions based on the analysis of actual material. Mental development is influenced by the application of knowledge, skills and

abilities in practice, with the optimal combination of creative and reproductive methods.

The text of the textbook uses various technologies, types of exercises (research, presentations, creative tasks), individual and group forms of work, and creates important prerequisites for the broad disclosure of individual characteristics of each student.

With the help of the structure and mechanism of the criteria-based assessment system specified in this methodological guide, it is possible to carry out developmental training focused on results, organize independent search activities of students, and carry out training in all sections of the discipline, namely:

1) methods of geographical research
2) cartography and geoinformatics
3) environmental management and geo-ecology
4) geo-economics
5) geopolitics
6) country studies
7) global problems of humanity

Each student can objectively assess the level of functional literacy development based on the knowledge gained in grades 9-10.

The difference between the teaching technology "Three-Dimensional methodical system" (TMS) and others is the three-dimensionality of all components of the methodological system (goals, content, methods, forms and means). Each component of the methodological system has a hierarchical relationship with each other. First of all, the goals of the three levels of development arise independently of each other. Intermediate results that are gradually achieved are put in the intended form (to measure a certain number of points). In accordance with the goals of each level, a sequence of level test tasks is selected that complement, deepen, and complicate [11].

Goal setting in geography lessons is one of the most problematic stages of pedagogical activity. Under the goal statement, we must understand that the goal is a model of the result.

1. Knowledge is the result of the process of cognitive activity of students. Knowledge means only the result of knowledge that can be logically or actually justified.

2. Category – memorizing and reproducing the studied material – from concrete facts to a complete theory.

3. Understanding is a universal thinking associated with the assimilation of new content. This category indicates the transformation of the material from one form of expression to another, the interpretation of the material, the assumption of the further course of the event-explains the facts, rules, and principles.

4. Application – the ability to use the learned material in specific conditions and new situations.

5. Analysis – geographical analysis - allows you to compare a variety of spatial information and present the results of the analysis in a form that is easy to understand.

6. Synthesis is the process of joining or combining previously disparate concepts into a whole. This category refers to the ability to combine elements to get a whole that has novelty.

7. Evaluation – indicates the ability to evaluate the value of a particular material.

The use of TMS technology in the learning process and the use of Bloom's taxonomy (Fig. 1) allow us to achieve positive results, in particular, students:

a) master the skills of self-study using the research method;

b) must be evaluated for each group. To do this, at the end of the lesson, three-level test tasks are performed that complement each other, deepen and complicate.

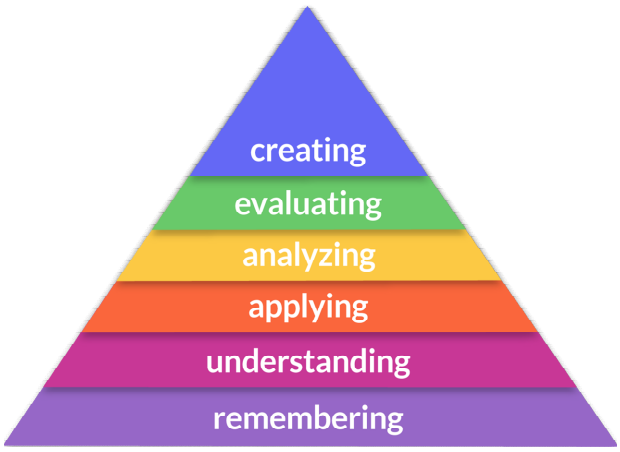

Fig. 1. Bloom's taxonomy of educational goals in the cognitive sphere [12].

In the course of completing the task, the student will get the appropriate score, depending on their ability.

With the traditional and correct completion of all tasks of the first level, he will receive 5 points, for the second level – 4 points, for the third-3 points. Having scored 12 points in the sum, his level of knowledge corresponds to the rating of "five". When performing SOR and SOC, there must be feedback between the student and the teacher. A corresponding score is given for each topic. A distinctive feature of this training technology is the "three-dimensional methodological system".

As a result, each student:

- receives a guarantee for alternative training;
- describes the ability of the students;
- a talented child gets the opportunity for all-round development;
- increasing interest in learning by gaining points on the "plus" rating system (based on the new qualimetry).

If in traditional education the primary role in the educational process is played by the teacher, now the student is active, i.e. he is trained by himself. In traditional teaching, the teacher provides the appropriate information to the student, and the student only listens and perceives the material. In the classroom, most often used reproductive methods (lecture, question-answer, exercise, etc.).

Currently, the student is looking for himself, he is learning. The lesson provides problem-based learning (solving the situation, thinking the child, "brainstorming", debates, etc.). At the lesson, the teacher performs a managerial role, orienting students.

The main attention is paid to identifying individual opportunities, research abilities, taking into account the interests of each student.

The student's activity is evaluated by many personal qualities (intellectual development, speech culture, independence, self-regulation, initiative, responsibility, etc.). Each student is compared to himself, not to another student. The student is given the opportunity to self-evaluate.

In this technology, both individual and group forms of training are the main ones. The main goal of group learning is to attract students to work together in small groups. In such a group, the student does not lose his identity. If necessary, students can turn to each other for help, solve common problems, i.e. there is a process of mutual learning. During the lesson, each student can not only evaluate their achievements or understand their shortcomings, but also see how they affect the overall result.

The individual form of training allows students to perform certain tasks and teaches them to be responsible for the result of completing tasks in front of themselves and the teacher. Such forms of training develop the student's self-confidence, stimulate the personal quality of honor and self-esteem.

With the development of a schedule for this technology, it is necessary to divide all topics into modules.

A module is a large, large-scale topic or Chapter consisting of several paragraphs. The peculiarity of this planning is that each Chapter (or module) ends with three final sessions:
- thematic independent work consisting of level tasks;
- correctional work;
- control work consisting of level tasks.

Step 1: "know task"
- be able to read a map;
- mastering the program for creating diagrams, tables, etc. from the computer science course;
- ability to describe and characterize the geographical position of countries;
- knowledge of geographical and geopolitical terms.

Step 2: "understanding task"
- understanding the purpose of the types and methods of research;
- why is it important to explore the territory of countries;
- why do political maps change;
- what factors influence the development of countries and territories.

Step 3: "application task"
- use of aerospace imagery and mapping techniques;
- use of conventional signs and symbols for zoning and modeling of topics and research objects;
- use of various programs to perform practical work;
- assessment of the geographical and geopolitical situation of individual countries using GIS technology.

Step 4: "analytic task"
- using tables and maps of the textbook, analyze geo-economics, geopolitics of the countries of the world and Kazakhstan;
- creating a database, conducting zoning and modeling, give a comprehensive analysis of the research topic.

Step 5: "synthesis task"
- applying different methods of training, identify gaps and opportunities to identify prospects and prediction;
- as a result of practical work, draw conclusions and make recommendations.

Step 6: "evaluation task"
- during expert evaluation, determine the objectivity and correctness of problem solving, which is evaluated by the teacher or by the students themselves;
- individual and group work.

Special attention is paid to the preparation of control and measurement materials, the use of information and communication technologies (ICT), working with internet resources, etc. As a result, the ability of students to competently and creatively use information and communication technologies in the educational process, in their free time and when communicating is ensured. The new training model implies the widespread use of ICT in various forms: test cases, training programs and platforms, electronic resources, and the Internet. The urgency of the transition to new forms of education based on the principles of using computer technologies is also emphasized [13].

Students develop skills for searching, processing and producing information, exchanging data and ideas, interacting, evaluating, and improving

Its work with various hardware and applications. For the purpose of studying the discipline, the following interactive classes are provided: business game; case-technologies; work in small groups. It is also recommended to organize meetings with scientists, travelers, and employees at the factory.

The teacher needs to be creative in their work, adapt to the structure of the lesson, modify methods, and use auxiliary tools that include working with students.

Students are offered the following types of work:
- independent understanding of the main educational and additional material;
- preparation of a message-report, abstract, PowerPoint presentation, poster, cluster, map diagram;
- project, practical, research, creative activities;
- independent, individual, paired work.

3 Conclusions

The educational and methodical complex is prepared by practical teachers and scientists who are well aware of the age characteristics of students.

This educational complex is innovative in nature, meets the requirements of modern society in the system of new knowledge in the education and comprehensive development of the individual.

There are also positive aspects of the program. Through personal and social development, students will learn to define, revise, and evaluate the values of society and personal values. They will also develop skills that will allow them to evaluate their own abilities, work independently, as well as in a team and make decisions. But the content of the curriculum is not worked out, because they noticed a discrepancy in the distribution of hours by section. The section "Nature management and

geo-ecology" occupies a third of the content. The educational program requires the following skills from the teacher:
- formulate training goals to achieve results;
- build a learning process for the organization of learning materials;
- prepare training materials in accordance with the training goals;
- use the potential of the information environment for the educational process;
- create conditions for the advanced development of students in the personal and activity orientation;
- evaluate current results aimed at achieving the set goals;
- to lead them to find ways to solve the problem that has arisen in front of them;
- conduct and prepare the educational process, so that all individual abilities of students are taken into account;
- use more tasks so that they work in groups and in pairs;
- make multi-level questions so that they approach the issue in more depth;
- a more serious approach to developing students' critical thinking. Thus, the author's collet, who wrote a textbook on the updated program, paid special attention to the development of a methodological guide, taking into account the above. Educational and methodical complex on geography of the 11th grade, tested in order in eighty schools of the Republic of Kazakhstan.

In this period, the main drawbacks are writing textbooks strictly according to the program. Do not allow authors to include certain aspects of educational geography.

Despite the ubiquity of digitalization, there is a weak material and technical base of schools. During testing of new generation textbooks, schools found limited access to the Internet and multimedia and office equipment, outdated equipment, and incomplete equipment

According to teachers, at the initial stage, there is a decrease in academic performance. Some students are disorganized because from grades 7 to 11, topics and sections are repeated. As a result, students have little knowledge of the basics of geography such as geographical patterns, Geology, tectonics, and cartography. Especially the sections Geoinformatics, geo-economics, geopolitics are mastered with difficulty. Below we attach the content of the author's updated textbook of the 11th class of the SHD:

The introduction of the updated content of secondary education did not take into account the training and retraining of schoolteachers. Short-term courses on the open program did not give the desired result.

The transition to the updated program will require the modernization of the entire education system. In order to make this transition, we need to start the changes with ourselves and with the training of teaching staff in educational institutions.

The system of geographical education in schools and universities that has developed in Kazakhstan over the past five years, especially now, is in a state of disintegration, which is manifested in connection with the introduction of an updated program in secondary schools without taking into account the readiness of teachers and schools themselves.

If until recently, the main complaint of teachers was the incompleteness of school geographical education, which is illogically distributed among classes, in particular, the very principle of teaching geography, we ask the question - what exactly it should be.

In view of the current situation and according to the authors of teachers-practitioners of geography, the geographical model of education should have the following structure.
- in grade 7, study the basics of physical and economic geography;
- in the 8th grade study of physical geography of Kazakhstan;
- in the 9th grade study of economic and social geography of Kazakhstan;
- in the 10th grade geo-economics (world) and Geoecology;
- in the 11th grade, country studies and global problems of humanity.

Starting from the 2020–2021 school year, students will be engaged in the expanded program. Thus, from grade 7 to grade 11, textbooks were written, and courses were developed. Thus, the updated program cycle will be fully implemented. The authors suggest that starting from the 2021–2022 academic year, it is necessary to update the content of the program according to the new structure. In the Republic, textbooks for grades 8–9 are available, but it is necessary to make an adjustment in accordance with the program. For the 10th grade, it need to write a new textbook on geo-economics and geo-ecology, as well as for the 11th grade. There are 3–4 years to write these textbooks. We believe that the use of research methods in high school will be justified. In grades 7–8, the section "Methods of geographical research" causes difficulties in understanding.

The authors understand that the proposed structure of geographical education will cause controversy, so offering this structure, we are waiting for rational proposals. We want to solve and find an answer to some questions from the current situation.

Modernization of Kazakhstan's education, accompanied by the transition to the updated content of training, is aimed at improving the quality of training, a personal-oriented approach to learning, and increasing motivation in studying specific disciplines. That is why the implementation of these recommendations in the educational process is particularly relevant.

The modernization of the educational sphere is taking place against the background of deep political and socio-economic transformations in the world and in Kazakhstan's society. Everything that is happening is connected with the transition to geopolitical and market relations. The task of methodologists from near and far abroad is to study the experience of geographical education and apply it in the educational process of their countries.

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The use of digital models of hemodynamics for the development of the 21st century skills as a components of healthcare competence of the physical education teacher

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Abstract. The article explores the use of digital models of hemodynamics to improve the health-saving competence of Physical Education teachers in postgraduate education through the integrative development of critical thinking and digital skills. The digital skills and critical thinking of a Physical Education teacher are relevant components of the 21st century skills system and are components of the health competence of a Physical Education teacher whose improvement is an important educational condition for the implementation of the sustainable development concept. The use of digital hemodynamic models, together with dialogical maieutics, reflexive and interactive educational practices, is an effective innovative educational technology that promotes the integrative development of digital skills, critical thinking, and the formation of fundamental and practically oriented morphology-based knowledge of cardiovascular system. Formed digital skills, critical thinking and knowledge of cardiovascular morphophysiology in Physical Education teacher is presented as a personal and intellectual condition for the prevention of sudden cardiac death of children and other cardiac pathology in the educational process during physical activity. The results of the study confirm the effectiveness of the use of digital models of hemodynamics to improve the health-saving competence of Physical Education teachers in postgraduate education through the integrative development of critical thinking and digital skills.

1 Introduction

Today, the global issue of preserving civilization and the Earth is building sustainable systems for securing a sustainable future. The focus of their formation is also the development of 21st century skills [1]. "The Sustainable Development Report 2019" identifies six SDG (Sustainable Development Goals) transformations that are necessary to ensure sustainable development [2]: Education, Gender, and Inequality; Health, Well-being, and Demography; Energy Decarbonization and Sustainable Industry; Sustainable Food, Land, Water and Oceans; Sustainable Cities and Communities; Harnessing the Digital Revolution for Sustainable Development.

The transformations highlighted by the researchers J. Sachs, [2] for the purpose of SDG operationalization are indicated [2]. They are necessary for the development of technologies, attracting effective investments, ensuring optimal management, coherence of political decisions, maintaining equality of all segments of the population. Transformations are closely related and interdependent. In particular, improving education contributes to the achievement of sustainable development goals in health, the environment and reducing inequalities [2].

Human health within the modern paradigm of sustainable development, the actual component of which is optimal motor activity, is considered as an anthropological phenomenon congruent with the conservation of the Earth and contributing to the achievement of the goals of sustainable development. A significant person who can effectively and professionally implement these requests for physical activity and preserve the health of children is a Physical Education teacher and trainer. Improving the health-saving competence of a Physical Education teacher [3] in postgraduate education is based on the idea of developing a critical thinking of a teacher and digital skills that are relevant components of "the 21st century skills system".

The concept of critical thinking is formed by J. Dewey on the basis of the cognitive and practical significance of life practices and experiences, humanistic intentions and the idea of respect for the individual [4]. The philosopher defined it as "reflective thinking", the

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ultimate intellectual goal of education, individual and social value [4]. As E. Ivunina points out, critical thinking is characterized by: systematic, consistent, multi-perspective, metacognitive, reflexive, multi-level, argumentative, non-dogmatic, logical [5]. According to A. Koroleva a significant aspect of the critical thinking of the roots of which are in antiquity is the dialogical-mothic context of its formation and realization, as well as the fact that it is the mental basis of socio-critical pedagogy [6]. Critical thinking according to J. Dewey contributes to "... reducing social evil." [7, p. 4; 8, p. 10]. A valuable aspect of critical thinking is that it is aimed at developing democracy [8, p. 10-11; 9].

V. Osadchyi explored the development of digital skills through the use of Internet resources, educational content management systems, social services, mobile technologies, artificial intelligence technologies, cloud technologies [10]. V. Bykov [11] emphasizes the enhancement of computer training at all levels of education, the careful use of digital educational resources and software, with the obligatory involvement of scientists and teachers in their creation. V. Bykov and M. Leshchenko revealed the theoretical and methodological foundations of the formation of digital humanistic pedagogy with the convergence of physical and virtual learning spaces [12]. O. Klochko, V. Nagayev, V. Klochko, explored ways to implement a person-centered paradigm using an empowerment approach to ensure sustainable personal development in the use of computer-oriented systems to shape the digital skills of future managers [13]. As part of O. Klochko i V. Fedorets health-saving approach, we have developed models for detecting signs of digital-related violations and predicting the risks of Internet addiction [14].

This study uses the methodological potential of the development of S. Semerikov and I. Teplitskyi dedicated to the application of ideas of fundamentalization [15]. Researchers draw attention to the need to: "preserve the core of content, which by its very nature must be conservative; learning basic competencies" [15, p. 251]. Effective methodological avenues for fundamentalization are the integrative use of hemodynamic models, digital skills and critical thinking.

From the point of view of P. Anokhin's teaching [16] on functional systems, health-saving competence of Physical Education teacher, as well as critical thinking, which we consider as a significant aspect of it, are specific "personality-mental" formations (functional systems) adapted to a certain type of activity. Specifying, we note that the health-saving competence of Physical Education teachers, critical thinking and information skills, besides universal general dimension and possibilities of application, have specific use, which is aimed at solving a relatively limited range of professional problems.

Such central problems are the vital and socially significant issues of preserving the life and cardiological health of children in the educational process. Accordingly, these problems determine the need for the Physical Education teacher to acquire knowledge of the phenomenology of the cardiovascular system and the ability to think critically in order to preserve the life and health of children. In these problems the disclosure of the phenomenology of the cardiovascular system is central and determining knowledge of hemodynamics (blood movement science) [17; 18; 19; 20] and their ability to use in professional activity. This is due to the fact that hemodynamic disorders that can occur as a result of motor activity or under the influence of other factors underlie the development of acute cardiac pathology and, above all, sudden cardiac death [21], which is an urgent problem of youth sports in all countries of the world. Really existing life and learning situations and physical exercises and motor actions can contribute to the formation of hemodynamic disorders and pose a risk to the cardiac health of the child. Therefore, in order to reduce the risks to the health and life of the child Physical Education teacher, it is necessary to develop appropriate intellectual tools, the significant components of which are critical thinking [4; 5; 6; 7; 8; 9] and digital skills [10; 11; 12; 13; 14]. Critical thinking and digital skills are necessary for understanding and life-oriented interpretation of pedagogical situations, training regimes, motor actions, exercises, techniques, technologies and motor phenomenology of the child based on the use of knowledge of hemodynamic phenomena and their ability to apply them in professional sphere. To develop hemodynamics knowledge at the level necessary for practically oriented understanding of hemodynamic risks by the Physical Education teacher in relation to the development of their health skills, we interpret the critical thinking using actual digital thinking, including first and digital hemodynamic models.

In research, the problem of using digital models of hemodynamics to develop critical thinking and digital skills as components of the health-care competency of a Physical Education teacher in postgraduate settings has not been sufficiently addressed. Thus, this problem is relevant in the context of the development of 21st century skills to secure a sustainable future.

The aim of the study. Improving the health-care competency of a Physical Education teacher in postgraduate education through the integrative development of critical thinking and digital skills based on the use of digital hemodynamic models.

2 Methods of the research

The methods and approaches used in the study are: analysis, synthesis; statistical in particular regression analysis; questionnaire; competent [22], health-saving, ontological, medical hygienic, pathophysiological, pathopedagogical, hemodynamic, transdisciplinary, systemic, holistic, humanistic, preventive, psychological, anthropological, cultural, hermeneutic, axiological, epistemological, innovative, problematic.

We have used the methodological, epistemological and axiological potential of the concepts: knowledge transfer, sustainable development, "Care of the Earth" (A. Gore) [23], sociocultural "construction" of health and pathology (M. Foucault) [24].

We applied an intellectually oriented technique. The purpose of this technique was the integrative development of critical thinking and its digital skills of Physical Education teacher, as well as the formation of knowledge of hemodynamics. Diagnosis of the results of the study was conducted using the questionnaire presented below. The questioning procedure consisted in asking students to use digital hemodynamic models to answer questions.

In this questionnaire, the correct answer for all questions is "No". In addition to assessing the formation of critical thinking, this questionnaire aims to determine the level of knowledge of hemodynamics.

Questionnaire of Fedorets-Klochko to assess the formation of critical thinking of a Physical Education teacher (trainer) based on the interpretation of hemodynamic knowledge:

1) From the standpoint of knowledge of hemodynamics, the presence of protective movements and a sharp decrease in the student's desire to actively participate in Physical Education indicates the normative state of his cardiovascular system and the presence of laziness, passivity and unwillingness to exercise. ("Yes","No").

2) From the standpoint of hemodynamic knowledge, the presence of a significant desire of the student to sit after or during physical activity indicates that he or she is neglected to exercise and lacks willpower. ("Yes","No").

3) Significant and rapid increase in blood in a large circle, including depot (spleen and liver) due to physical activity indicates good heart training and a good level of physical fitness, which indicates the need to increase the intensity of training. ("Yes","No").

4) Significant and rapid increase in blood volume in the large circulatory cycle against the backdrop of reducing it in the small circle resulting from exercise results in better provision of tissues with oxygen and nutrients, which in turn is a physiological condition for the need to increase the intensity of training. ("Yes","No").

5) The accumulation of blood in the depot, spleen and liver during physical activity is caused only by the pumping function of the left ventricle of the heart. ("Yes","No").

6) The opening and expansion of many vessels of the microcirculatory bed (capillaries, precapillaries, arterioles, venules, etc.) will only lead to positive results in improving local circulation. ("Yes","No").

7) The accumulation of blood in the depot in the liver and spleen during sleep is due to increased work of the left ventricle. ("Yes", No").

8) Increased work of the left ventricle directly promotes active inflow ("pushing") of blood to the right atrium. ("Yes","No").

3 Results and discussion

In the context of implementing sustainable development strategies, we consider the Sustainable Development Goals (SDGs), which are most correlated with the studied components of the development of the health-saving competence of a Physical Education teacher [1]: 1) Transformation No 1. Education, Gender, and Inequality. Involving ministries of Education This transformation covers education investment, social protection, regulation of labor legislation and research. 2) Transformation No 2. Health, Well-being, and Demography. The transformation involves group interventions to provide Universal Health Coverage (UHC). Promoting a healthy lifestyle and ensuring social key factors for health and well-being are important. 3) Transformation No 6. Harnessing the Digital Revolution for Sustainable Development. This transformation is one of the keys to ensuring that all the goals of a sustainable future are met. Accordingly, if properly used, it contributes to the sustainable development and implementation of these goals.

The physical competence of a Physical Education teacher is a holistic "intellectual-personal-activity" phenomenon formed by the integration of many components [3]. Against this background, and considering the recommendations of the World Economic Forum on 21st century skills, we consider in the study only some of the components of the Physical Education teacher's competency, namely, Critical Thinking and Digital Skills [25; 26; 27; 28] Critical Thinking and Digital Skills are one of the 21st century skills that are important for (implementing the concept of sustainable development) of securing a sustainable future.

So, we consider the factors influencing the SDG index [1] (Table 1): Ensure healthy lives and promote well-being for all at all ages (GOAL 3, Good health and well-being); Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all (GOAL 4, Quality education), that includes the factors information and communications technology (ICT) skills. By region of study SDG Ukraine is classified as Eastern Europe and Central Asia. Therefore, we will look at the Good Health and Well-Being and Quality Education indices of the 23 countries in the region (except for 4 countries for which there are no SDG data). According to the Sustainable Development Report 2019 [1], the average SDG for Eastern Europe and Central Asia is 70,4, Good health and well-being – 77,11, Quality education – 89,2.

In order to perform regression analysis on the basis of the experimental data in Table 1, we build a mathematical model (1) that describes the behavior of the SDGs depending on the change in the factors Good health and well-being, Quality education that affect it:

$$y = f(x_1, x_2) + \varepsilon, \quad (1)$$

where y is the dependent variable SDG (response, regressor); x_1, x_2 are independent variables (regressors, predictors) respectively Good health and well-being, Quality education; ε is a random error.

The purpose of the regression model is to investigate the impact of Good health and well-being, Quality education on the SDGs in Eastern Europe and Central Asia, to which Ukraine also belongs.

We construct a two-factor linear regression model $y = F(x)$:

$$y = b_0 + b_1x_1 + b_2x_2 \quad (2)$$

Table 1. SDGs and its Impact Factors: Good health and well-being, Quality education, 2019 y. [1].

No	Country	Global Index Score, y	Good health and well-being, x_1	Quality education, x_2
		(0-100)	(0-100)	(0-100)
1	Afghanistan	49,65	38,71	23,67
2	Albania	70,27	82,21	93,40
4	Armenia	68,77	78,52	89,75
5	Azerbaijan	70,46	75,29	90,76
6	Bosnia and Herzegovina	69,39	80,26	99,38
7	Belarus	77,44	81,73	96,79
8	Cyprus	70,14	92,83	97,02
9	Georgia	68,91	73,21	98,33
10	Croatia	77,79	87,09	87,36
11	Kazakhstan	68,71	75,77	90,98
12	Kyrgyz Republic	71,62	70,08	91,07
13	Moldova	74,41	74,82	82,66
14	North Macedonia	69,38	80,00	88,32
15	Malta	76,11	92,69	97,49
16	Montenegro	67,25	79,88	96,27
17	Romania	72,73	80,63	84,17
18	Russian Federation	70,94	78,06	97,21
19	Serbia	72,49	84,16	94,29
20	Tajikistan	69,23	70,15	95,96
21	Turkmenistan	64,26	67,77	99,64
22	Ukraine	72,81	71,76	92,55
23	Uzbekistan	71,13	77,62	93,62

The matrix form of the equation (2):

$$Y=BX, \quad (3)$$

where

$$Y = \begin{pmatrix} y_1 \\ y_2 \\ \dots \\ y_{23} \end{pmatrix}, X = \begin{pmatrix} 1 & x_{1\,1} & x_{2\,1} \\ 1 & x_{2\,1} & x_{2\,2} \\ \dots & \dots & \dots \\ 1 & x_{23\,1} & x_{23\,2} \end{pmatrix}, B = \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix}. \quad (4)$$

The coefficients b_1, b_2, b_3 of the regression model (2) are found by the formula [29, p. 87]:

$$B=(X^TX)^{-1}X^TY, \quad (5)$$

where X^T is the matrix, transposed to the matrix X; $(X^TX)^{-1}$ is the inverse of the matrix (X^TX).

As a result of the calculations, a regression model is constructed:

$$y = 37,0 + 60,38x_1 + 0,04x_2. \quad (6)$$

The calculated coefficient of determination R^2=0,67. This value is medium, closer to high. Estimated value of Fisher-Snedecor F-test F=20,39 [29]. Tabular value $F_{0,5;2;20}$=3,49. $F>F_{0,5;2;20}$. According to the Fisher-Snedecor F-test, the regression equation is significant. Given the value of the coefficient of determination and the Fisher-Snedecor F-test, we consider this equation (6) to be usable.

Physical activity is a key contributor to almost all Sustainable Development Goals. Appropriate measures and attracted investment to increase physical activity should be a priority for each country. In addition to promoting the health and well-being of people of all ages, they aim to address other priorities of achieving the Sustainable Development Goals. Regular physical activity contributes to the prevention and treatment of noncommunicable diseases, reduces the level of their risk factors, promotes the health of the population throughout life. Table 2 shows the benefits of implementing strategies to increase physical activity that can help achieve [30].

The need to improve the digital skills of Physical Education teachers in postgraduate education is due to the fact that they are a component of the professional competence of the teacher, refer to the skills of the 21st century [1] and are integral to the goals of sustainable development.

The digital competences of Physical Education teachers in terms of postgraduate education are components of which digital skills are characterized by systematic, holistic, integrative nature. Their main components are the ability to: navigate the information space; perform actions with data in a professional activity; use common and application software. The development of digital skills of a Physical Education teacher is based on a competent approach [22]. The development of personality culture, as well as the use of the humanistic potential of ideas of multiculturalism, tolerance, Europeanization, safety and high quality of life. In the context of pedagogical integration [31], we emphasize the need to improve digital skills in combination with critical thinking.

The term “critical thinking” was first used by the classic American pragmatist J. Dewey in “How We Think” [4] in 1910. The philosopher draws attention to the reflexive [4; 8, p. 9], problematizing [8, p. 11; 9], active, practical, humanizing [1], the life-giving character of critical thinking. Important for the unfolding of the phenomenology of health is the eudemonic aspect of critical thinking aimed at achieving individual happiness [7, p. 4; 8, p. 10] and life success. J. Dewey’s merit is also that he sees critical thinking not only as a mental tool, but as an actual educational strategy and purpose [9]. For the development of the health-saving competence of a Physical Education teacher, the development of critical thinking is relevant because it has a mental setting for identifying [5] and understanding inconsistencies. That is, critical thinking contributes to the objectification, evidence, reasoning, logic that is necessary for a health-oriented understanding of the phenomenon of the person and his health. Critical thinking is the basis of a specific mental “tool” of a physical education teacher.

Critical thinking is directed at the formation of objectified and realistic understandings, interpretations and visions by the Physical Education teacher of the child and his or her health. Critical thinking as analytical, synthetic, practically oriented in its mental nature, is accordingly close to the digital skills that are represented as cognitive matrices formed on the basis of

certain algorithms. This defines the educational logic of its integrated formation.

Table 2. Co-benefits of policy action to increase physical activity [30].

Economic, social and environmental co-benefits	decrease	Sustainable Development Goals	growth	Economic, social and environmental co-benefits
Road accidents; Noncommunicable diseases (NCDs)	↓	Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	↑	Healthy weight
		Goal 3. Ensure healthy lives and promote well-being for all at all ages	↑	Well-being and quality of life; Cognitive function; Mental health
		Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	↑	Academic achievement; Early childhood development
		Goal 5. Achieve gender equality and empower all women and girls	↑	Empowerment among women and girls
Health costs	↓	Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	↑	Life skills; Economic growth; Productivity; Job creation; Tourism
		Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	↑	Sustainable infrastructure
Inequalities	↓	Goal 10. Reduce inequality within and among countries	↑	
		Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable	↑	Air quality; Community cohesion; Sustainable transport
Fossil fuel consumption	↓	Goal 12. Ensure sustainable consumption and production patterns		
		Goal 13. Take urgent action to combat climate change and its impacts	↑	Mitigation of climate change; Environment protection
		Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	↑	Environmental conservation
Discrimination	↓	Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels		
		Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	↑	Partnerships for a more active world

Accordingly, critical thinking [4; 5; 6; 7; 8; 9] is decisive and system-organizing in the professional activity of a Physical Education teacher aimed at maintaining health. It is also significant for its social and professional adaptation and self-realization.

An important methodological aspect of this issue is the need to improve the critical thinking of the teacher by studying normative and pathological anthropological phenomena in particular on the basis of digital hemodynamic models [32; 33].

The urgency of the use of digital hemodynamic models is determined by the professional need to form a practically oriented knowledge and understanding of the functioning of the cardiovascular system in the teacher of Physical Education, interdependent with regard to the specific motive activity and features of biomechanics. In addition, it is important for the teacher to understand the health and risk situations of children who are experiencing physical activity in physical education classes. Therefore, the Physical Education teacher must have critical thinking to deal with such problems effectively. A structural and defining aspect is that critical thinking is seen as a relevant component of health-saving thinking.

It is important to take into account that hemodynamic disorders can occur during motor activity sharply, that is relatively quickly and without prior signs or manifestations, which requires immediate and optimal decisions. It should also be born in mind that these hemodynamic phenomena tend to have rapid and rather unpredictable dynamics. Thus, critical thinking is an actual intellectual tool for decision making.

In order to improve the critical thinking of the Physical Education teacher, as well as to correlate the formation of practically oriented knowledge of the physiology of the cardiovascular system, we used digital

hemodynamic models of our own development and features: CVSS (Cardio-Vascular Simulation System) [19], BioUML [32], Sorin C5 System [33] and other (Figure 1, Figure 2).

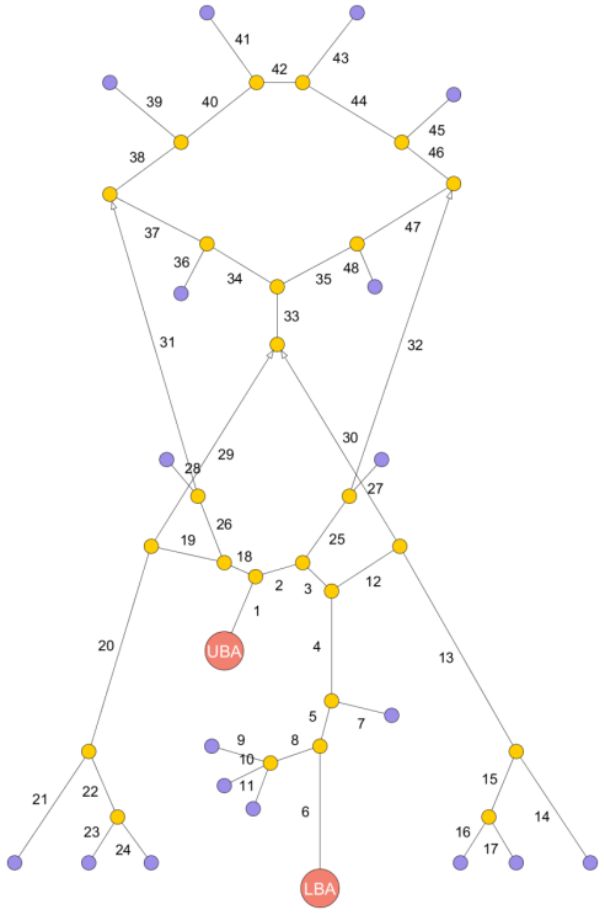

Fig. 1. One-scale model of hemodynamics for modeling the basilar artery [19].

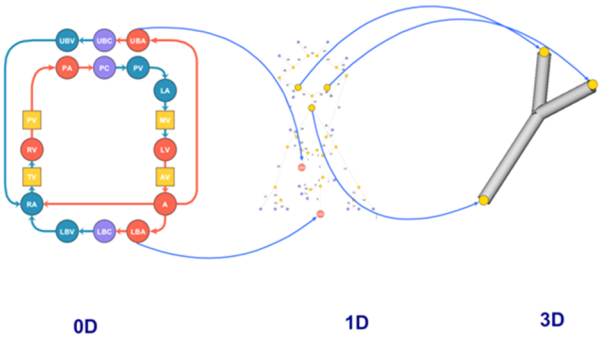

Fig. 2. Multiscale hemodynamics model for basilar artery modelling [19].

In addition to the use of digital hemodynamic models, the development of critical thinking has been utilized by auto-dialogic, reflexive and interactive practices, solving pedagogical problems, as well as analyzing specific real-life problems, questions, phenomena and experiences.

The study was made in 2017-2018. During the training courses for Physical Education teachers' positive dynamics of the development of critical thinking have been identified. The study involved 157 Physical Education teachers. The study was conducted at: Drohobych Ivan Franko State Pedagogical University, Chernihiv Regional Institute of Postgraduate Education Ushynsky, Sumy Regional Postgraduate Pedagogical Education Institute, and Mykolaiv Regional Postgraduate Education Institute. To determine the dynamics of the formation of critical thinking and knowledge of hemodynamics, we used "Questionnaire Fedorets-Klochko assessment of the formation of critical thinking Physical Education teacher (trainer) based on the interpretation of knowledge of hemodynamics" (described above in research methods).

In the control group, which consisted of 75 people, hemodynamics studied without the use of digital hemodynamic models, the results are presented in Figure 3. The experimental group consisted of 82 people; the results are presented in Figure 4. The study of hemodynamics in this group was conducted both through the use of digital hemodynamic models and applying the techniques used in the control group.

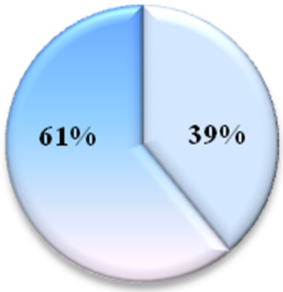

Fig. 3. Results of the questionnaire aimed at assessing the formation of critical thinking and knowledge of hemodynamics of Physical Education teachers, who studied without the use of digital hemodynamic models (control group).

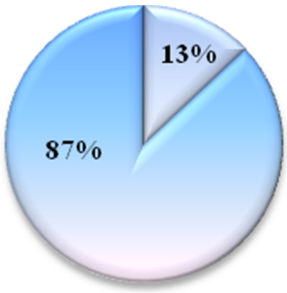

Fig. 4. Results of the questionnaire aimed at assessing the formation of critical thinking and knowledge of hemodynamics of Physical Education teachers, who have used digital hemodynamic models in training (experimental group).

As a result of the questionnaire aimed at assessing the formation of critical thinking and knowledge of hemodynamics of Physical Education teachers, the following results were obtained: teachers who studied without the use of digital hemodynamic models the number of correct answers is 61%; teachers who have used digital hemodynamic models in training have correct answers of 87%. So, the difference in correct answers between the two groups is 26%. As can be seen from Figure 3 and Figure 4, improving critical thinking and developing knowledge of the hemodynamics of

Physical Education teachers in postgraduate education has a positive dynamic, which is formed by the use of hemodynamic models.

The positive dynamics of the results are explained by the following factors: teachers' motivation to familiarize themselves with the indicated direction in connection with the need for knowledge of hemodynamic mechanisms of cardiac pathologies occurrence; the need to prevent sudden cardiac death; application of digital hemodynamic models in the educational process; using known knowledge in practically oriented interpretations and formats.

Conclusion

A significant cultural and educational condition for the implementation of the Sustainable Development Goals is health preservation and physical activity. This determines the need to improve the health-care competency of a Physical Education teacher and his professionalism, based on the values and goals of sustainable development, as well as through the transfer of health and information knowledge.

Based on the analysis of the coefficient b_1=0,38 equation (6) we can conclude that the relationship between the variables y and x_1 (SDG and Good health and well-being)) is direct. As the value of the variable x_1 per unit increases, the value of the variable y will increase by 0,38 (that is, with the increase in the unit Good health and well-being, the SDG will increase by 0,38). The impact of Quality education on the model-built SDG is less. b_2=0,04 (equation (6), the relationship between the variables y and x_2 (SDG and Quality education SDG) is straightforward. With the increase in the value of the variable x_2 per unit, the value of the variable y will increase by 0,04 (that is, with increasing Quality education per unit, SDG will increase by 0,04).

One of the reasons for this result may be that in the current context, the life cycle of professions is shortening. Currently, the field of education remains conservative, with some programs unchanged for many years. Therefore, the right set of skills is relevant, which in the future will help change the profession and retrain, as well as professionally and personally improve and be socially adapted. The future is variable and may evolve in different scenarios. Therefore, we identify skills that are designed for variant scenarios of the future and can help adapt to such changes.

At present, the development and improvement of 21st century skills, namely critical thinking and digital skills, is relevant to ensure the achievement of sustainable development goals. In the process of improving the health-saving competence of a Physical Education teacher (trainer), an integral and interdependent skill development of the teacher is the integrative and interdependent development of critical thinking and digital skills based on the study of hemodynamics through the use of digital hemodynamic models. The development of critical thinking, digital skills and the formation of hemodynamic knowledge are aimed primarily at solving the current problem of modern education for the prevention of sudden cardiac death and other cardiac pathology in the educational process.

Digital hemodynamic models are intellectual learning systems that have significant educational, practical, epistemological, methodological, heuristic and axiological potentials. The methodological value of digital hemodynamic models is that they are ontologically, visually, holistically, as well as problematically and procedurally oriented, reveal the phenomenology of the cardiovascular system.

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Research of the somatic health of student youth using information and communication technologies

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Abstract. The article is devoted to the issues of using information-communication technologies for monitoring the physical health of students, which will enable them to be more successful, adaptable to the environment and current social changes in the future. The study included determining the level of somatic health by the method of G. L. Apanasenko. The rapid assessment had a fairly wide range of individual indicators of overall health, as well as cardiovascular and respiratory system functionality. The analysis of the conducted studies clearly indicates the need for constant monitoring of the indicators of physical development and somatic health of students throughout the study period. In order to objectively evaluate somatic health and to track it in dynamics, the students proposed the information and communication technology "Health Portfolio" developed by the authors. The implementation of such monitoring model and information program provides an automated assessment of the functionality of the human body and is accurate, informative and physiologically sound. Due to the increase in the amount of all kinds of information, as a pledge of future professional success of modern students, there is a problem of motivation of healthy lifestyle and involvement of students in independent motor activity.

1 Introduction

With environmental degradation, poor nutrition, sedentary lifestyles, the risk of deteriorating of overall health state increases. This set of negative factors eventually leads to the fact that the available functional reserves of the organism become insufficient to adequately respond to external influences of different nature [1, 2, 3].

Motor activity is an essential component of a healthy lifestyle and one of the ways to form, maintain and promote health. Physical activity has a stimulating effect on almost all life support systems. Due to the growing flow of information, the constant use of computer and digital technologies in education and everyday life has led to a restriction of motor activity. Since motor activity is an effective method for the prevention of cardiovascular pathology, metabolic disorders, diseases of the musculoskeletal system, the question arises of the need to monitor the state of health and reserve capacity of the body nature [2, 4, 5, 6].

Despite a large number of studies [2, 6, 7, 8] devoted to studying the health status of students, the physical abilities of their body, there is a shortage of express ICT methods for assessing and introspecting an individual's somatic health. In connection with the foregoing, the aim of the study is a comparative analysis of the somatic health of students with different levels of motor activity.

In connection with the above data, the aim of the study was to analyze the somatic health of students and develop a monitoring model for evaluating the functional capabilities of an organism.

2 Results and discussions

To consider the external and internal factors affecting the quality of life of students, the components of the students' lifestyle were studied.

When assessing the state of health of respondents using the self-assessment method, it was found that 54.30% of female students and 67.20% of male students rate it positively (Fig. 1).

In the minds of students, such concepts as "youth" and "health" are inseparable. Obviously, therefore, quite optimistic outlook on the state of their health, the level of personal physical culture is inherent in students [2, 4].

Based on the data obtained by us, it follows that students represent a category of the population with increased risk factors, which include nervous and mental strain, constant disturbances in diet, labor and rest.

In the lifestyle of students, there is often a lack of health care: disorder, randomness, expressed in untimely food intake, systematic lack of sleep, a short stay in the fresh air and lack of motor activity.

The index of motor activity of students was determined by the method of O. S. Kuts [9]. The standard of change in motor activity was the weekly index of motor activity (IMA). Scales were used to obtain reliable and objective results in the study, followed by grouping of all types of movements. The first group includes daily

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movements, and the second group includes exercises related to physical training and sports. The results obtained were processed using the following formula:

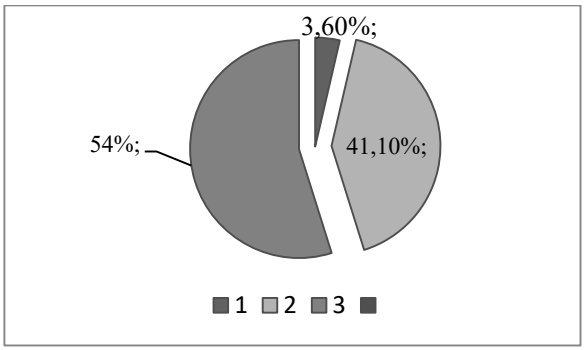
$$IMA = (\sum HMA + \sum PA) / T_T \times 100\% \quad (1)$$

where *IMA* is the index of motor activity per week (%);

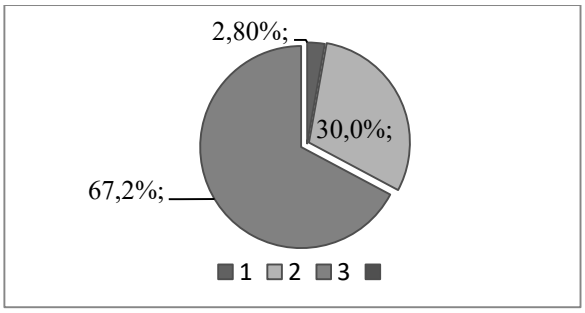
T_T – time of activity;

Σ*HMA* – the amount of time spent on household movements (min);

Σ*PA* – the amount of time spent on exercise and sports (min) [8].



Female students



Male students

Fig. 1. The results of self-esteem of their health by students: 1 – significant deviations in health state; 2 – minor deviations in health state; 3 – no complaints, almost healthy.

According to the results of the conducted questionnaire of general and physical-fitness motor activity, the time spent by students on active exercise of physical tasks is insufficient, and they belong to the group of people with low level of physical activity. The analysis of the answers showed that male students spend on average 3,42 ± 0,07% of time per week for daily physical activity, and female students spend 2,39 ± 0,05% of time for physical motor activity. The weekly motor activity index was 5,81 ± 0,14% and had no significant differences between the sexes.

Assessment of the somatic health of students was carried out according to the method of G. L. Apanasenko, which characterizes the main indicators of body functions: the heart rate at rest, the time to restore the heart rate to its original level after 20 squats in 30 sec.; growth, body weight, vital lung capacity (VC), hand dynamometry, blood pressure [4, 6, 10]. The choice of this method is due to the fact that it allows to comprehensively determine the functional state of the organism according to the indicators of the cardio-respiratory and muscular system, which are formalized in quantitative units (points) and are related to the level of individual health (Table 1). This technique consists of determining anthropometric and functional indicators and their indices.

Table 1. Level of indicator of mass-height (Quetelet index) of students, %.

Sex	Age	Indicator Level				
		Low	Below the average	Average	Above the average	High
Male	17-18	–	1,7	36,8	–	–
	19-20	0,8	0,8	31,8	–	–
	21-22	0,8	1,7	25,8	–	–
Total		1,6	4	94,4	-	–
Female	17-18	0,8	5,3	30	–	–
	19-20	2,3	3,9	28,4	–	–
	21-22	–	3,9	25,4	–	–
Total		3,1	13,1	83,8	-	–

The basis of the developed system is based on the indicators of physical development (height, body weight, vital capacity of the lungs, wrist dynamometry), the state of the cardiovascular system at rest and in the recovery period after dosed physical activity. Express assessment is based on the relationship between overall endurance, the volume of physiological reserves and the manifestation of economization of the function of the cardiorespiratory system [4, 6, 7].

Mass-height index (Quetelet index), showing the ratio of body weight to growth was determined by the formula:

$$QI = M / R \quad (2)$$

where: *QI* – Quetelet index;

M – body weight (g);

R – height (cm)

According to the indicators of mass-height ratio, the average level of this indicator among male and female students prevailed. This indicates that they do not have defects with body proportions, and the rest of students have marked deviation of this indicator in the direction of increasing or decreasing weight in accordance with physiological norms.

Thanks to the data obtained, the life index (LI) was calculated, showing the extent of oxygen which lungs can provide the whole body when it is in active motion. Life index according to Apanasenko is determined by dividing VCL (ml) by body weight (kg), i.e. which lung volume accounts for 1 kg of body weight [4, 6]:

$$LI = VCL / M \quad (3)$$

where: *LI* is the life index (ml / kg);

VCL – vital lung capacity (ml);

M – body weight (kg).

So, the greater the body weight of a person, the higher the need for its tissues in oxygen, the more effective the lungs should be to ensure adequate ventilation in normal conditions. Accordingly, under increased load, these needs will increase many times over.

The life index is an important indicator of the quantitative expression of students' health, as it is an informative indicator of the conformity of external respiration and weight with the relevant norm [6].

The indicators of life index show that there are slight differences between boys and girls. Thus, among the students studied, the average life index values were 31,7% of boys and 26,9% of girls. However, there were a higher number of girls who had below the average and high indicators of life index (37.5 and 1.5% respectively), while boys did not have high indicators and only 11.5% of male students had indicators of life index at levels higher than average. At the same time, 30% of low-score students had insufficient pulmonary ventilation (Table 2).

Table 2. Comparative characteristics of students' indicators of life index, %.

Sex	Age	Indicator Level				
		Low	Below the average	Average	Above the average	High
Male	17-18	13,4	8,3	12,5	4,1	–
	19-20	13,4	5,8	10	4,1	–
	21-22	9,2	6,7	9,2	3,3	–
Total		36	20,8	31,7	11,5	-
Female	17-18	2,3	9,2	7,7	15,3	1,5
	19-20	5	7,7	9,2	13	–
	21-22	3	6,9	10	9,2	–
Total		10,3	23,8	26,9	37,5	1,5

Power index is required for qualitative assessment of muscle strength. Muscle strength means the ability of muscles to overcome external resistance or counteract it through muscular effort. Muscle strength is manifested in three main forms: maximum muscle strength (depends on the number and thickness of the muscle fibers), high-speed force and endurance.

Measurement of the strength of the hand (wrist dynamometer) was performed using a wrist dynamometer. The power index is the percentage of the muscle strength of the hand to body weight. Thanks to the data obtained, the power index (PI) was calculated by the formula:

$$PI=HP\ /M \quad (4)$$

where: *PI* – power index (kg);
HP – hand power (kg);
M – body weight (kg).

Analyzing the indicators of wrist dynamometry, it should be noted that in young men the initial level of hand power on the right and left arm was not significantly different. The same trend is observed in girls. The analysis of physical development showed that the range of distribution of morphological indicators in them is quite wide. Calculating the power index, we noticed that most of the students studied were characterized by low and below average levels (Table 3).

Thus, in young men, this figure was 35,0% – a low level and 30,0% – below the average level. Girls showed a tendency to improve – 38,3% of the respondents had above average and high level of the power index.

Thus, among all the investigated, the high level of the power index was determined only at 12,6%, the low level – 48,0% (Fig. 2).

The Robinson index characterizes the functional state of the cardiovascular system.

$$IR = RHR \times AT_{max} / 100 \quad (5)$$

where: *IP* – Robinson Index;
RHR – resting heart rate (beats / min);
AT_{max} – maximum blood pressure (mm of mercury).

Table 3. Level of indicators of the power index of students, %.

Sex	Age	Indicator Level				
		Low	Below the average	Average	Above the average	High
Male	17-18	20	5,8	9,1	6,8	1,7
	19-20	20,8	1,7	4,2	4,2	0,8
	21-22	18,4	3,3	5,8	1,6	0,8
Total		35,0	30,0	19,1	12,6	3,3
Female	17-18	3,8	17,7	6,2	5,4	3,1
	19-20	5,4	18,5	3,8	2,3	4,6
	21-22	3,8	16,2	3,1	4,6	1,6
Total		13	52,4	13	12,3	9,3

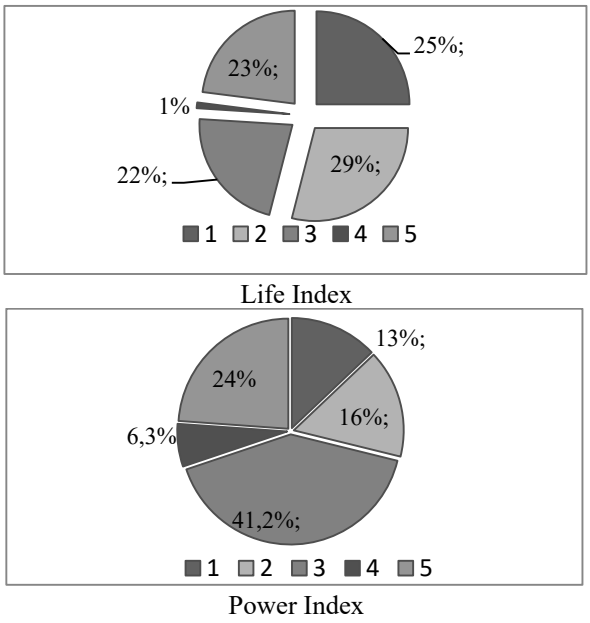


Fig. 2. Robinson index **i**ndicator and Ruffier index **i**ndicator by students: 1 – above the average level; 2 – the average level; 3 – below the average level; 4 – high level; 5 – low level.

A low Robinson index score indicates a violation of cardiovascular activity. A high Robinson index at rest may indicate low aerobic capacity of the body and therefore low somatic health [2, 4].

The average of the Robinson index was observed in 53,3% of boys and 63,8% of girls. In other physiological indicators of the functional state of the cardiovascular system of the organism indicate the general pattern of change in the state of regulatory systems, which demonstrate the tension of adaptive mechanisms, which should be taken into account when analyzing exercise programs with this contingent (Table 4).

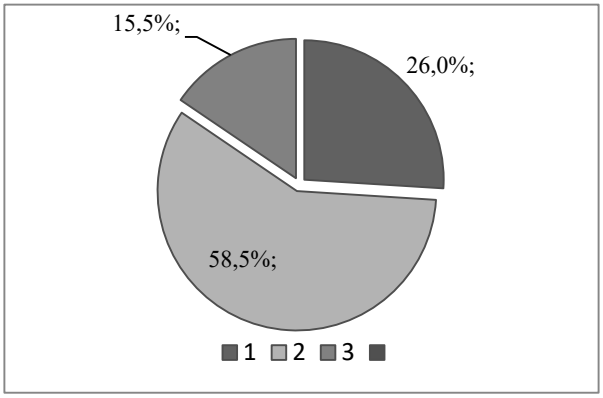
Thus, the high and low level of the Robinson index was not found in the studied students, above the average – 26,0%, the average – 58,5%, below the average – 15,5% of the studied students (Fig. 3).

The Ruffier Index shows the recovery time to the "normal rhythm" after increased heart rate and characterizes the magnitude of the performance reserve.

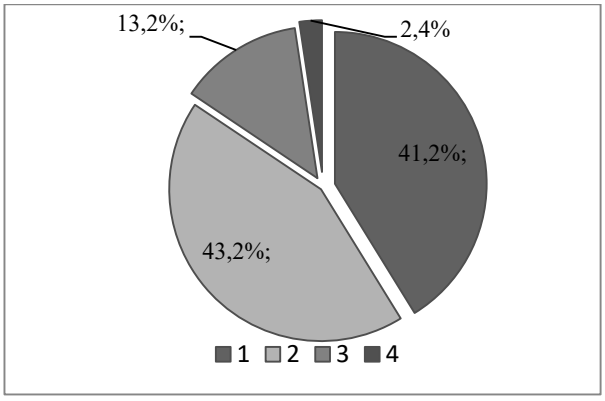
The higher this reserve, the less time it takes for the heart to recover its original working rhythm after a high load [4, 5] (Table 5).

Table 4. The value of the Robinson index, %.

Sex	Age	Indicator Level				
		Low	Below the average	Average	Above the average	High
Male	17-18	–	4,2	20	14,2	–
	19-20	–	6,7	15	11,6	–
	21-22	–	2,5	18,3	7,5	–
Total		–	–	53,3	33,3	–
Female	17-18	–	5,4	23,8	6,9	–
	19-20	–	6,9	20,8	7,0	–
	21-22	–	5,4	19,2	4,6	–
Total		–	–	63,8	18,5	–



Robinson index



Ruffier index

Fig. 3. Robinson index **i**ndicator and Ruffier index indicator by students: 1 – above the average level; 2 – the average level; 3 – below the average level; 4 – high level.

Knowing how the values of heart rate and blood pressure change during exercise, it is possible to evaluate the adequacy of the cardiac response to this load and to evaluate the effectiveness of the cardiovascular system as a whole.

There have been no cases of low Ruffier index scores among students, indicating a lack of adaptation reserves and adaptation of the cardiovascular and respiratory systems, which limits the physical capacity of the student body. Students need a significant increase in the daily amount of motor activity.

Therefore, below the average level of recovery time after 20 squats in 30 seconds was identified in 13,2% of respondents, the average level – 43,2%, above the average – 41,2%, high – 2,4%.

Table 5. The level of the indicator of the recovery time of the functional state of students, %.

Sex	Age	Indicator Level				
		Low	Below the average	Average	Above the average	High
Male	17-18	-	3,3	19,2	15	0,8
	19-20	-	4,2	14,2	13,3	1,6
	21-22	-	5,8	11,8	10	0,8
Total		-	13,3	45,2	38,3	3,2
Female	17-18	-	6,2	11,5	16,9	1,6
	19-20	-	2,3	17,7	14,6	-
	21-22	-	4,6	14,6	10	-
Total		-	13,1	43,8	41,5	1,6

Summing up the points accrued for each indicator, a quantitative assessment of the level of health is given (Table 6, 7). The higher the score, the better your health.

Table 6. The scale of assessment of the level of physical condition of male students by the method of G. L. Apanasenko [4].

Indicator	Sex	Indicators Level				
		Low	Below the average	Average	Above the average	High
Mass-height index	male	≥501	451-500	401-450	375-400	≤375
Points		(-2)	(-1)	(0)	(-1)	(-2)
Life Index	male	≤50	51-55	56-60	61-65	≥66
Points		(0)	(1)	(2)	(3)	(5)
Power Index	male	≤60	61-65	66-70	71-79	≥80
Points		(0)	(1)	(2)	(3)	(4)
Robinson Index	male	≥111	95-110	85-94	70-84	≤69
Points		(-2)	(0)	(2)	(3)	(4)
Ruffier Index	male	≥3	2-3	1,3-1,59	1,0-1,29	≤ 1
Points		(-2)	(1)	(3)	(5)	(7)
Overall health score, points		≤4	5-9	10-13	14-15	17-21

With this rating system, safe health (above average) starts at 14 points. This is the lowest amount of points that guarantees the absence of clinical signs of the disease. Its decline is accompanied by a progressive increase in the number of diseases and a decrease in the body's functional reserves to a dangerous level bordering on pathology. It should be noted that the absence of clinical manifestations of the disease is not yet indicative of stable health. Average level of health can be regarded as critical. Its further decrease already leads to clinical manifestation of diseases [2, 6, 7].

The average value of the initial assessment of the general level of somatic health of students aged 17-22 years was 11,4 points (Table. 8). This indicator of assessment of the overall level of somatic health, according to the age dynamics of somatic health, is 1,1 points lower than the age norm and corresponds to the norm for the older age group, which indicates an increase in their biological age endurance [4, 6].

Table 7. The scale of assessment of the level of physical condition of female students by the method of G. L. Apanasenko [4].

Indicator	Sex	Indicators level				
		Low	Below the average	Average	Above the average	High
Mass-height index	female	≥451	401-450	375-400	400-351	≤350
Points		(-2)	(-1)	(0)	(-1)	(-2)
Life Index	female	≤40	41-45	46-50	51-56	≥57
Points		(0)	(1)	(2)	(3)	(5)
Power Index	female	≤40	41-50	51-55	56-60	≥61
Points		(0)	(1)	(2)	(3)	(4)
Robinson Index	female	≥ 111	95-110	85-94	70-84	≤69
Points		(-2)	(0)	(2)	(3)	(4)
Ruffier Index	female	≥3	2-3	1,3-1,59	1,0-1,29	≤ 1
Points		(-2)	(1)	(3)	(5)	(7)
Overall health score, points		≤4	5-9	10-13	14-15	17-21

Table 8. Assessing the overall level of students' somatic health by G. L. Apanasenko [4]

Average student overall somatic health score, points	Age norm of average values of an indicator of general somatic health	
	Age	Assessment of the general level of somatic health, points
11,4	20-30	12,5
	31-40	9,2
	41-50	8,7
	51- 60	6,7

The vast majority of students showed low and below average health level (51,6% girls and 52,5% boys). Average health level was observed in 28,3% of boys and 36,1% of girls. Based on the results obtained, it can be argued that the percentage of girls with average health (7,8%) is slightly higher than that of boys, but most students still remain outside the safe level (Fig. 4).

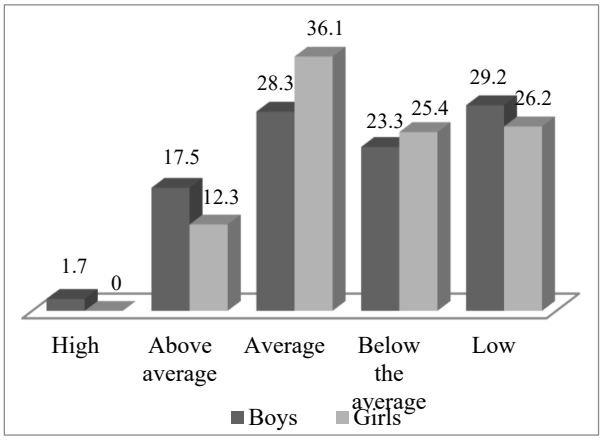


Fig. 4. The ratio of the indictors level of physical state of students of different sex according to the method of G. L. Apanasenko, in %.

However, one cannot help but see the contradictions between the imaginary state of health and physical fitness and their real indicators.

Comparative analysis of students' self-esteem of health and express assessment by the method of G. L. Apanasenko showed the need for constant monitoring of indicators of physical development and somatic health of students throughout the entire period of study.

Thus, in order to objectively evaluate somatic health and track it in dynamics, the students proposed the information-methodical model of health that was developed by the authors (Fig. 5).

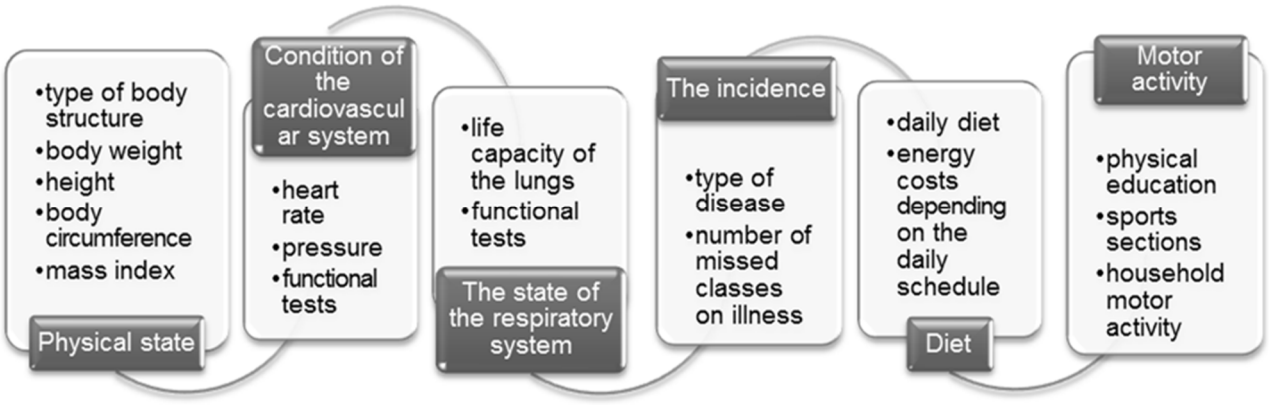


Fig. 5. Model of health.

We have developed an electronic product "Health Portfolio" (Fig. 6), which stores information about the student (name, group, specialization), his data, necessary for calculating health indicators, and monitoring results.

The essence of the program is to provide each student with the opportunity to demonstrate his health potential and sustainable motivation to a healthy lifestyle.

The electronic portfolio allows to enter information about the current state of health, automatically calculate health indicators, visualize the dynamics of changes in health indicators, track the results of work done by the student.

Using the portfolio, the student has the opportunity to conduct an independent analysis of the dynamics of

changes in his state of health and choose, in accordance with the result, the most suitable way of life for him.

Student Health Portfolio				
	Training periods			
	I year	II year	III year	IV year
Mirzoeva Antonina				
Year of birth 2000				
Female				
Faculty - Chemical-biological				
Height, cm	179	179	179	179
Weight, kg	56	56	58	60
Heart rate, beats / min	80	79	74	75
Systolic pressure, mm of mercury	102	102	104	102
Diastolic pressure, mm of mercury	72	73	78	70
Pulse pressure, mm of mercury	30	29	26	30
Static balancing, sec.	60	60	60	60
Ruffier sample, units	10 Satisfactorily	11 Weak	11 Weak	13 Weak
Vital capacity of the lungs, ml	3300	3300	3400	3400
Dynamometer indicator, kg	31	30	30	33
Overall health score	7 Average	8 Average	9 Average	9 Average
Health group	preparatory	preparatory	preparatory	preparatory

Fig. 6. "Health Portfolio".

This software product allows to individualize the process of changing the physical state of student youth, as well as to form a stable motivational and value attitude to their health.

3 Conclusions

Express-estimation of somatic health level determination according to G. L. Apanasenko method showed that students had lower than average and low levels of somatic health.

Considering the results of the research, it is possible to state in general about unsatisfactory health state of student youth, which confirms the necessity to introduce and use the developed electronic product "Health Portfolio". Visualization of indicators of physical health, as well as the annual correlation of its indicators will encourage the student youth to reconsider their lifestyle, to be more attentive to their health.

Information-communication technologies are an effective source of promotion of healthy lifestyles among young people in order to gain professional competence and competitiveness of future professionals.

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Implementation of education for sustainable development principles in the training of future software engineers

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Abstract. The article examines the professional training of future software engineers in higher education institutions in the context of the implementation of the Sustainable Development Goals set by the UN General Assembly, as well as the Education for Sustainable Development (ESD) principles. A number of contradictions that arise in the course of this training are mentioned on the example of training of future object-oriented programming engineers. The UNESCO documents on education for sustainable development, scientific sources on the professional training of future software engineers, as well as the integration of sustainable development into relevant educational programs are analyzed. The methodology and results of experimental work carried out with the aim of overcoming existing contradictions, promoting sustainable development of information technology education and implementation of ESD principles in the process of professional training of future software engineers are presented. In particular, the organizational and methodological conditions, that were implemented into the educational process, and experimental data are presented. The effectiveness of the experimental work was proved by statistical verification of the reliability of the obtained data.

1 Introduction

The achievement of the Sustainable Development Goals set in 2015 by the UN General Assembly [1] is linked to the training of highly qualified professionals from all sectors of the economy who are capable of reflection, professional mobility and lifelong learning, aware of responsibility for the results of their activities. Such training is based on Education for Sustainable Development (ESD) principles.

According with UNESCO Roadmap "ESD empowers learners to take informed decisions and responsible actions for environmental integrity, economic viability and a just society, for present and future generations, while respecting cultural diversity. It is about lifelong learning, and is an integral part of quality education. ESD is holistic and transformational education which addresses learning content and outcomes, pedagogy and the learning environment. It achieves its purpose by transforming society." [2, p. 12].

Intensive development of the information technology and the need to overcome the numerous challenges facing humanity, lead to an increase in requirements for professionals whose activities are creation, implementation and maintenance of software. The professional training of such specialists in the bachelor's and master's degrees of higher education in Ukraine is carried out in the specialties of the field of knowledge "Information Technology", in particular "Software Engineering" and "Computer Science". In order to ensure that the level of professionalism of graduates of these specialties corresponds to the requirements of society, effective procedures of updating the content, forms, methods and means of training should be implemented in higher education institutions on the basis of systematic monitoring of the state of the industry and a balanced combination of fundamental, applied and humanitarian components of higher education.

This is the opinion of Ukrainian researchers V. Kruhlyk and V. Osadchyi [3], A. Striuk and S. Semerikov [4], T. Vakaliuk, V. Kontsedailo, D. Antoniuk, O. Korotun, I. Mintii and A. Pikilnyak [5], O. Markova, S. Semerikov, A. Striuk, H. Shalatska, P. Nechypurenko and V. Tron [6], H. Chemerys, K. Osadcha, V. Osadchyi and V. Kruhlyk [7] and others.

An important area of professional work of software engineers is the software development using an object-oriented approach, so graduates of higher education institutions should understand its fundamental principles, be able to use object-oriented programming languages, to apply existing and make their own decisions, to decompose and compose tasks, to document the process of building an object model, etc. The lack of the necessary capabilities of the developers is one of the reasons for the low quality of software products, which in some cases pose a threat to the sustainable future. Other threats include focus on current tasks and immediate goals, lack of understanding of global economic, environmental and social issues, opportunities to overcome or minimize them at the level of individual IT-professionals or businesses, the impact of IT-products

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on the present and future, and responsibility to future generations.

Therefore, there is a need to create in the higher education institutions the conditions for students to develop appropriate professional competences.

Domestic and foreign scientists have thoroughly developed conceptual foundations and examined some aspects of higher education and professional training of future software engineers. However, insufficient attention is paid to developing their professional competence in the study of object-oriented programming (OOP), as well as to acquire the knowledge and skills necessary to pursue activities with a view to sustainable development goals. Therefore, there are contradictions between: the need to combine the fundamental theoretical and thorough practical training of future software engineers as highly qualified specialists and the limited time of studying the disciplines of the vocational training cycle; the necessity of using abstraction, decomposition and composition in the process of studying OOP and insufficient level of abstract-logical thinking in students; high level of complexity of OOP educational content and insufficient readiness of higher education students to systematic cognitive self-activity; possibility to demonstrate object-oriented approach on the example of large projects and traditional use of educational tasks with limited content; the society requirements for the professional training of software engineers and the students' lack of awareness of these requirements; lack of knowledge on sustainability issues and the need to promote a sustainable future in professional life and daily life.

Purpose of the article: to present the results of experimental work carried out with the purpose of overcoming the mentioned contradictions, promoting sustainable development of IT education and implementation of ESD principles in the process of professional training of future software engineers.

2 Literature review

As I. Mulà et al. emphasise "The world is shaped by an education system that reinforces unsustainable thinking and practice" [8, p. 798]. So, it is very important to transform an education system taking into account aims of sustainability and sustainable future. Education for sustainable development principles are substantiated in numerous UNESCO documents [2; 9; 10; 11] and discussed in scientific papers [8; 12].

Internationally recognized ESD principles are named by D. Tilbury and I. Mulà. They are the next: futures thinking; critical and creative thinking; participation and participatory learning; partnerships; systemic thinking [11, p. 5]. Moreover, there are pointed out key ESD learning themes (e.g., gender equality; biological diversity; ecological principles, ecosystems; natural resources management; health and well-being; consumerism and ethical trade; rural and urban development; corporate social responsibility) that are critically significant to the sustainable development agenda [11, p. 6].

Implementation of ESD principles in the process of professional training of future software engineers in higher education institutions is in different ways, in particular: deep informatization of the educational process [5; 6; 13; 14]; enhancing opportunities for professional mobility and lifelong learning for IT professionals through the development and implementation of intelligent means of recognition of qualifications and competences obtained in different countries and educational institutions [15]; improving educational programs for the short cycle of vocational training [16]; improving the content, forms, methods and tools of object-oriented programming [17]; introduction of sustainability issues to the content of educational programs [18; 19; 20; 21] and others.

A detailed analysis of scientific literature on the problems of OOP training future software engineers was carried out in [17].

Researchers in the training of computer science and software engineers note that sustainable development issues are hardly addressed in relevant university education programs. However, software engineers should take their share of responsibility for sustainability because of growing of IT's productivity in combination with cutting down of life cycles and growing resource problems of our planet [18, p. 454]. In this regard, it is necessary to determine the mechanisms for introducing sustainable development issues into university computer science and software engineering curricula, as well as motivating students and teachers to address them. In foreign pedagogical practice these issues have been investigated sufficiently well.

B. Penzenstadler and A. Fleischmann offer a strategy for integrating the concept of sustainability into a degree course scheme across three stages: 1) to propose a seminar and form a core of interested people; 2) to give a lecture series for broaden the awareness for sustainability; 3) to establish sustainability as topic by integrating it into the syllabus of appropriate software engineering lectures with teach-the-teacher seminars. During a seminar student should examine chosen issue and to present their topic in class. They are offered such seminar topics as: "Climate killer internet? Energy-efficient nets and systems have a notable impact", "Climate change research and software engineering for climate research", "Marketing for sustainability – how can I make it matter for software engineers?" etc. [18, pp. 455-456].

D. H. Fisher, Z. Bian and S. Chen emphasize the nexus between sustainability and computer science and the necessity to integrate sustainability science and engineering into computing education [19, p. 95]. They survey two levels of integration of sustainability into computer science higher education (the course level and the course component level) and give different examples of such combination. Scientists identify the course-level integration as introducing computer science courses that focus on topics at the intersection of computing and sustainability. These are such courses as "Computing, Energy, and the Environment", "Seminar on Computational Sustainability: Algorithms for Ecology and Conservation" etc. Component-level integration is

implemented by introducing lectures, exercises, and projects, with sustainability themes into computer science courses that do not have a sustainability focus, such as courses in computer organization, databases, and artificial intelligence [19, p. 93-94].

Three sustainability integration strategies are offered by Y. Cai: 1) developing a new course named "green computing" covering selected sustainability and green computing topics; 2) designing and developing independent green computing learning modules and projects that can be easily plugged into the existing computer courses; 3) an integrative and transformative approach to completely re-design some computing courses with sustainability as one of the top priorities [20, pp. 525-526].

L. M. Hilty and P. Huber [21] consider that sustainable development is an important part of the curriculum of ICT-related study programs and content is strongly significant to interest students in it. They present results of empirical investigation aimed identifying topics with the greatest potential to motivate students on sustainability. Researchers reveal five clusters of such topics, namely: "ICT impacts on sustainability"; "Material resources for ICT hardware: Informal recycling"; "ICT as an enabler: Saving material and energy: Videoconferencing example"; "Resource consumption: Global distribution"; "Rebound effect: General concept" [21, p. 652].

An example of IT-students participation in project aimed solution one of sustainability tasks – "provide safe, non violent, inclusive and effective learning environments for all" [1] – is given in [22].

3 Research methodology

The ideas of education for sustainable development were realized by us in the process of experimental and experimental work on forming the professional competence of future software engineers in the process of studying object-oriented programming, necessary for further successful activity in the specialty.

The experiment was conducted during 2015-2018 on the basis of higher education institutions of Ukraine, in particular, the Bogdan Khmelnytsky Melitopol State Pedagogical University. 135 second-, third- and fourth-year students of full-time education studying 6.040302 "Informatics" field and 122 "Computer sciences and information technologies" speciality have taken part in the qualifying and forming stages of the pedagogical experiment. The number of the control group (CG) was 69 people, experimental (EG) - 66 people.

We followed this sequence of pedagogical research [23, p. 10]:

1) comparison of the initial state of formation of components of professional competence in students of the control and experimental groups according to certain criteria and indicators, establishing the absence of statistically significant differences;

2) introduction of the developed organizational and methodological conditions for the formation of professional competence of future software engineers in the process of studying object-oriented programming in the experimental group;

3) comparison of the final state of formation of components of professional competence in students of the control and experimental groups according to certain criteria and indicators, establishing the presence of statistically significant differences.

In the course of this work, the levels of professional competence components of future software engineers identified by us in [17] were diagnosed:

- motivational: a set of motives that encourage higher education students to actively study OOP; their interest in the in-depth study and use of OOP in their further professional activities; readiness for self-development in object-oriented development;
- cognitive: development of abstract-logical thinking; possession of techniques of formalization, abstraction, decomposition and composition; understanding the fundamental basics of OOP and their implementation in different programming languages; set of theoretical knowledge of fundamental concepts and applied aspects of OOP;
- operational: formation of skills in object-oriented programming necessary for effective professional activity;
- reflexive: the ability to self-understand, analyze and evaluate yourself as a specialist and your actions in the current situation, in the past and in the future, as well as yourself as a member of the software development team.

Since the ECTS scale is used in the institutions of higher education of Ukraine to evaluate students' academic achievement, five levels of formation of these components of the professional competence of future software engineers have been identified:

- professional: certifies the formation of a component of professional competence at the level of an experienced software engineer and the ability of the student to enter professional activity as a mid-level specialist without additional training, corresponds to the level "A" of the ECTS scale;
- high: certifies the formation of a component of professional competence at the level of junior software engineer and the ability of the student to start professional activity and independent tasks without additional training, corresponds to the level "B" of the ECTS scale;
- sufficient: certifies the formation of a component of professional competence at the level of the junior software engineer and the ability of the student to start professional activity and independently perform tasks with additional training at the enterprise, corresponds to the level "C" of the ECTS scale;
- low: certifies the formation of a component of professional competence at the level of the novice programmer and the ability of the student to begin professional activity as a junior software engineer only under the direct supervision and with additional training at the enterprise, corresponds to the level "D" of the ECTS scale;
- critical: certifies the extremely low level of professional competence component and the student's lack of ability to take up professional work as a software

engineer, corresponds to the "E" level of the ECTS scale.

In the experimental group, the educational process was organized on the basis of the following organizational and methodological conditions [17]:

1) Formation of positive motivation for students to study and apply in future professional activities of OOP. The implementation of this condition included demonstration of examples of software development practice, meetings with leading specialists of IT enterprises, organization of group implementation of software projects, involvement of students in the discussion of practical aspects of the software engineer.

2) Formation of a cross-cutting content-activity line of studying OOP within the disciplines of the vocational training cycle. Within each successive course, fundamental concepts of object-oriented programming were repeated, and they were considered at a new level of complexity, taking into account the specifics of a particular area of software development.

3) Application of appropriate forms and methods of formation in higher professional qualifications. The implementation of this condition involved the implementation of various types of software projects, the use of training tasks in object-oriented programming, interactive teaching methods and game technologies.

4) Use of modern information and communication technologies in the process of education of students of OOP, namely: software for educational purposes, software development environments, visualization tools, training management systems, distance courses in academic disciplines and additional specialized online resources.

Some ESD ideas were implemented during the development of the students' program projects. In particular, they were offered project topics such as: developing programs for the statistical processing of observation data (demographic economic, meteorological, medical, biological, etc.); development of educational programs for students of general secondary education institutions (simulators, didactic games, etc.); development of programs for automation of separate production processes for enterprises of different industries, etc. In order to create quality software, students had to pre-analyze the problem given the problems of a sustainable future and the goals of sustainable development.

The measures envisaged by the pilot program were implemented within the training disciplines of the cycle of professional training: "Programming", "Object-oriented programming", "Cross-platform programming", "Web application programming and support".

To evaluate the likelihood of the experimental data obtained, a method of testing statistical hypotheses was used.

The hypothesis of the absence of significant differences in the average values of indicators of the formation of components of professional competence in students of control and experimental groups was tested using the Student's t-test (1) [24, p. 185].

$$t_{\text{emp}} = \frac{|\bar{X}_1 - \bar{X}_2|}{\sqrt{\frac{(n_1-1)\times\sigma_1^2+(n_2-1)\times\sigma_2^2}{n_1+n_2-2}\times\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}}, \quad (1)$$

where $\bar{X}_1$ and $\bar{X}_2$, σ_1^2 and σ_2^2, n_1 and n_2 – averages, variances, and volumes of the first and second samples, respectively.

Testing the hypothesis about the conformity of the samples to the normal law of distribution of random variables was performed using formulas (2) and (3) [25, p. 231-232].

$$A = \frac{\sum(x_i-\bar{x})^3}{n\times\sigma^3}, \quad m_A = \sqrt{\frac{6}{n}}, \quad (2)$$

$$E = \frac{\sum(x_i-\bar{x})^4}{n\times\sigma^4} - 3, \quad m_E = 2\times\sqrt{\frac{6}{n}}, \quad (3)$$

where A – asymmetry indicator, E – excess indicator, m_A and m_E – representativeness errors for each of these indicators, respectively.

Volumes of control and experimental groups $n_{CG} = 69$ and $n_{EG} = 66$ respectively. Number of degrees of freedom $k = n_{CG} + n_{EG} - 2 = 69 + 66 - 2 = 133$. Critical significance of the Student test for 133 degrees of freedom and significance level α=0.05: $t_{\text{cr}} \approx 1.98$.

4 Analysis of experimental results

4.1 Qualifying stage of the research

The empirical data obtained at the ascertaining stage of the pedagogical experiment gave reason to draw the following main conclusions:

1) future software engineers in the control and experimental groups found insufficient level of professional competence development: approximately one third to two thirds of students demonstrated low or critical level of professional competence components;

2) the initial level of professional competence in the two groups practically did not differ (the difference between the percentage of students at each level of education in terms of individual competence components did not exceed 3%), which testified to their homogeneity.

According to the results of estimation of the level of the motivational component of professional competence of future software engineers, 34.78% of students (24 persons) of CG and 34.85% of students (23 persons) of EG revealed low or critical level. At the same time, 46.38% of students (32 persons) of CG and 45.45% of students (30 persons) of EG showed sufficient level. So, after completing their first year, they understood the need for knowledge of object-oriented programming technologies and languages and were partially motivated to further study OOP.

According to the results of assessment of the level of cognitive component of professional competence of future software engineers, 68.12% of students (47 persons) of CG and 68.18% of students (45 persons) of EG have found low or critical level. This situation is

to a certain extent due to the fact that the first year focuses on the study of algorithmization, structural and procedural programming, and the mechanisms of OOP are mostly considered indirectly to the extent necessary for writing programs in development environments.

According to the results of estimation of the level of the operational component of professional competence of future software engineers, 75.36% of students (52 persons) of CG and 71.21% of students (47 persons) of EG revealed low or critical level. The reason for this is that at the end of the first year students have initial experience writing programs with classes and objects, but they do not yet use the full-scale OOP mechanisms.

As a result of assessing the level of reflexive component of the professional competence of future software engineers, 47.83% of students (33 persons) of CG and 48.48% of students (32 persons) of EG revealed low or critical levels. At the same time, 37.68% of students (26 persons) of CG and 34.85% of students (23 persons) of EG showed sufficient level, which testified to partial formation of ability to evaluate themselves as a student, member of academic group and software development team, as well as the results of its activities.

Valuation of the obtained data. The hypothesis about the absence of statistically significant differences in the average values of indicators of the formation of the components of students' professional competence in the control and experimental groups was performed using the Student's t-test, which was calculated by formula (1). Preliminary verification of sampling of the normal law of random distribution according to formulas (2) and (3) was carried out.

The null hypothesis H_0: $x_{CG} = x_{EG}$, there is no statistically significant difference between the samples, the average values of the indicators of the professional competence components of the students of the control and experimental groups are equal.

Alternative hypothesis H_1: $x_{CG} \neq x_{EG}$, there is a statistically significant difference between the samples. the average values of indicators of the formation of components of professional competence of students in the control and experimental groups differ significantly.

The results of testing these statistical hypotheses are given in Table 1.

Table 1. Results of valuation of the obtained data (qualifying stage of the experiment).

Components of professional competence	t_{emp}	Conclusion
motivational	0.47	For all components $t_{emp} < t_{cr}$. Hypothesis H_0 is accepted.
cognitive	0.33	
operational	0.12	
reflexive	0.01	

Thus, it is proved that there is no statistically significant difference in the levels of formation of the components of professional competence in students of the control and experimental groups at the qualifying stage of the pedagogical experiment, that is, the samples are homogeneous.

Based on the analysis of empirical data of the qualifying stage of the pedagogical experiment, it was concluded that the level of individual components, and therefore the professional competence of future software engineers was generally low and critical. In order to increase this level, the educational process and the study of object-oriented programming had to be organized in such a way as to ensure the acquisition and completeness of students' acquisition of basic and special knowledge of OOP (cognitive component), the effective formation in them of OOP skills and ability to use them in the process of development of various types of software projects (operational component), persistent high motivation to study OOP, its further use in professional activity, and self-improvement in this field in terms of programmatic development (motivational component), formation of ability to evaluate and responsible attitude to the results of their work and role in the team (reflexive component).

4.2 Forming stage of the research

The empirical data obtained during the formative stage of the pedagogical experiment gave reason to make the following generalizations:

1) the overall level of future software engineers' competence has increased: in both groups the increase in the number of students at the professional and high levels, as well as the increase in the average values of the indicators of the components of professional competence, but the changes in the experimental group were more significant;

2) the final levels of the components of students' professional competence in the experimental group exceeded the corresponding indicators in the control group.

On the basis of these data, a preliminary conclusion was made about the effectiveness of implementing the organizational and methodological conditions for forming the professional competence of future software engineers in the process of studying object-oriented programming in higher education institutions.

The results of the assessment of the level of the motivational component of professional competence of future software engineers revealed that in the experimental group the percentage of students with professional and high level was equal to 21.21% (14 people) and 42.42% (28 people) respectively. In the control group there were minor changes and this indicator was 10.14% (7 persons) and 18.84% (13 persons), respectively. A significant difference was observed in the indicators characterizing the number of students with low and critical levels: 6.06% (4 persons) and 3.03% (2 persons) in EG; 15.94% (11 persons) and 5.80% (4 persons) in CG respectively. The obtained data are presented in Fig. 1.

According to the results of assessment of the level of cognitive component of professional competence of future software engineers, it was found that in the experimental group the percentage of students with professional and high level became equal to 21.21% (14 persons) and 36.36% (24 persons), respectively. In the control group there were slight changes and this

indicator was 4.35% (3 persons) and 11.59% (8 persons) respectively. A significant difference was observed in the indicators characterizing the number of students with low and critical levels: 9.09% (6 persons) and 3.03% (2 persons) in EG; 28.99% (20 people) and 8.70% (6 people) in CG, respectively. The obtained data are presented in Fig. 2.

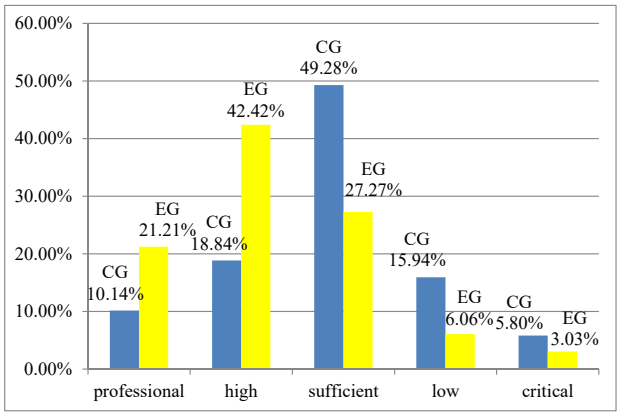

Fig. 1. Formation of the motivational component of the professional competence of future software engineers (forming stage of the experiment).

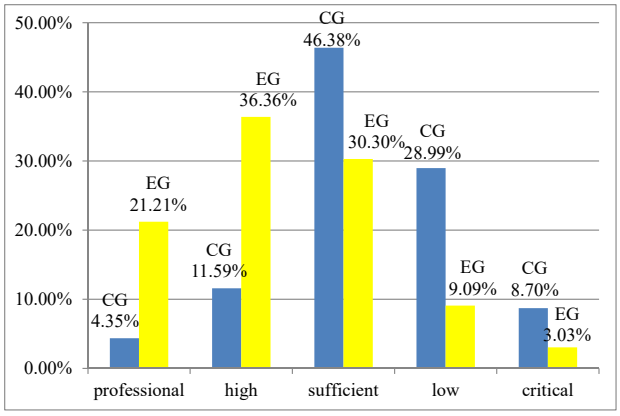

Fig. 2. Formation of the cognitive component of the professional competence of future software engineers (forming stage of the experiment).

According to the results of evaluation of the level of the operational component of professional competence of future engineers-programmers, it was found that in the experimental group the percentage of students with professional and high level was equal to 19.70% (13 persons) and 40.91% (27 persons), respectively. In the control group, there were slight changes and this figure was 5.80% (4 persons) and 15.94% (11 persons), respectively. A significant difference was observed in the indicators characterizing the number of students with low and critical levels: 9.09% (6 persons) and 3.03% (2 persons) in EG; 31.88% (22 persons) and 13.04% (9 persons) in CG, respectively. The obtained data are presented in Fig. 3.

According to the results of the evaluation of the level of the reflexive component of professional competence of future software engineers, it was found that in the experimental group the percentage of students with professional and high level was equal to 22.73% (15 people) and 30.30% (20 people), respectively. In the control group there were slight changes and this indicator was 10.14% (7 people) and 15.94% (11 people), respectively. A significant difference was observed in the indicators characterizing the number of students with low and critical levels: 6.06% (4 persons) and 3.03% (2 persons) in EG; 23.19% (16 people) and 8.70% (6 people) in CG, respectively. The obtained data are presented in Fig. 4.

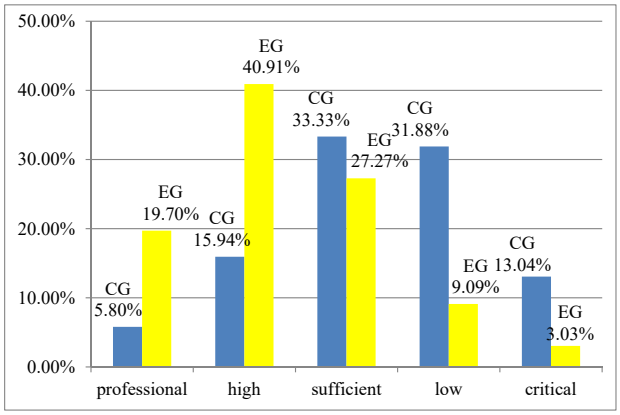

Fig. 3. Formation of the operational component of the professional competence of future software engineers (forming stage of the experiment).

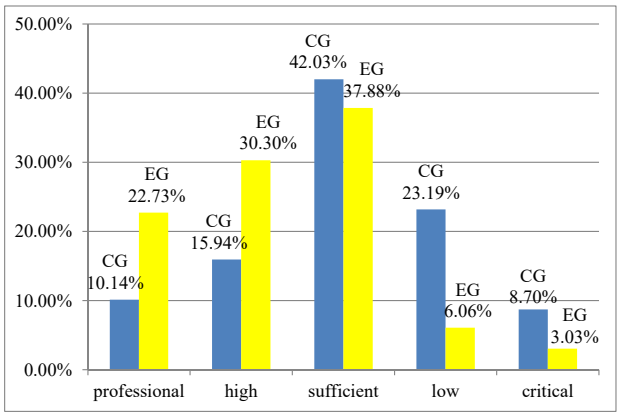

Fig. 4. Formation of the reflexive component of the professional competence of future software engineers (forming stage of the experiment).

Valuation of the obtained data. Testing of the hypothesis about the presence of statistically significant differences in the average values of the formation of components of students' professional competence in control and experimental groups, and therefore different levels of formation of professional competence was generally performed using the Student's t-criterion, which was calculated by formula (1). Preliminary verification of sampling of the normal law of random distribution according to formulas (2) and (3) was carried out.

The null hypothesis H_0: $x_{CG} = x_{EG}$, there is no statistically significant difference between the samples, the average values of the indicators of the professional competence components of the students of the control and experimental groups are equal.

Alternative hypothesis $H_1: x_{CG} \neq x_{EG}$, there is a statistically significant difference between the samples. the average values of indicators of the formation of components of professional competence of students in the control and experimental groups differ significantly.

The results of testing these statistical hypotheses are given in Table 2.

Table 2. Results of valuation of the obtained data (forming stage of the experiment).

Components of professional competence	t_{emp}	Conclusion
motivational	2.85	For all components $t_{emp} > t_{cr}$. Hypothesis H_0 is rejected, hypothesis H_1 is accepted.
cognitive	6.09	
operational	5.32	
reflexive	2.87	

Thus, the existence of statistically significant differences in the levels of formation of components of professional competence in students of control and experimental groups at the formative stage of pedagogical experiment was proved. This leads to the conclusion that the average difference is not accidental, but is the result of the implementation of the proposed organizational and methodological conditions for the formation of professional competence of future software engineers in the process of studying object-oriented programming.

5 Conclusion

Transformation of society to meet the goals of sustainable development is impossible without the active participation of each individual citizen. Training for such activities should be undertaken in education institutions of all levels based on Education for Sustainable Development principles.

The realization of the goals of education for sustainable development in the process of professional training of future software engineers in higher education institutions implies deep informatization of the educational process, enhancement of opportunities for professional mobility and lifelong learning, improvement of educational programs, introduction of issues of sustainability and content.

The contradictions that adversely affect the formation of the professional competence of future software engineers in the process of object-oriented programming study have been identified. In order to overcome the problems, organizational and methodological conditions for the formation of the professional competence of future software engineers in the process of object-oriented programming study at higher education institutions have been implemented.

In order to verify the effectiveness of the organizational and methodological conditions during 2015-2018, the research and experimental work was carried out. 135 second-, third- and fourth-year students of full-time education studying 6.040302 “Informatics” field and 122 “Computer sciences and information technologies” speciality have taken part in the qualifying and forming stages of the pedagogical experiment. There has been recorded an increase in the level of formation of the professional competence among students of the experimental group at the end of the formative stage of the pedagogical experiment, namely: the number of students with professional and high levels of the formation of the motivational component has increased by 43.94%, the cognitive component – by 50.00%, the operational and activity component – by 51.51%, the reflexive component – by 36.36%; the increase in average values of the indicators of the formation of the motivational component has been 34.95%, the cognitive component – 23.42%, the operational and activity component – by 23.40%, the reflexive component – 27.03%. The reliability of the obtained results has been verified using Student’s t-criterion: at the end of the forming stage of the experiment its empirical value (t_{emp}) for all the components of the professional competence exceeded the critical value ($t_{cr} \approx 1.98$). Thus, it was proved that the implementation of the developed organizational and methodological conditions contributed to improving the effectiveness of the formation of the professional competence of future software engineers in the process of the object-oriented programming studying.

In the process of experimental work, attention was paid to acquaint students with the goals and objectives of sustainable development. We believe that it is advisable to direct further research on the implementation of strategies for the introduction of training programs for engineering engineers of disciplines and individual modules aimed at familiarizing students with the problems of a sustainable future, forming in them an understanding of their role in solving these problems.

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Sustainability in Software Engineering Education: a case of general professional competencies

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Abstract. The article considers the application of the sustainable development concept to software engineering specialists training. A system of general professional competencies is designed to build sustainable professional competence of software engineering specialist: 1) ability for abstract thinking, analysis and synthesis; 2) ability to apply knowledge in practical situations; 3) ability to communicate in native language; 4) ability to communicate in a foreign language; 5) ability to learn and acquire up-to-date knowledge; 6) ability to search, process and analyze information from various sources; 7) ability to work in a team; 8) ability to act on the basis of ethical considerations; 9) commitment to preserving the environment; 10) ability to act in a socially responsible and conscious manner; 11) ability to realize the rights and obligations as a member of society, to recognize the civil society values and the need for its sustainable development, the rule of law, human rights and freedoms; 12) ability to preserve and enhance the moral, cultural, scientific values and society achievements based on an understanding of the history and patterns of the subject area development, its place in the general system of knowledge about nature and society and in the development of society, equipment's and technology, to use various types and forms of physical activity for active recreation and healthy lifestyle; 13) ability to apply fundamental and interdisciplinary knowledge to successfully solve software engineering problems; 14) ability to evaluate and take into account economic, social, technological and environmental factors affecting the sphere of professional activity; 15) ability for lifelong learning.

1 Introduction

The necessity to apply the sustainable development methodology to the training is shown by the historical and technological analysis of software engineering as a profession [45] and specialty in which specialists with higher education [46] are trained.

Nail K. Nuriev considers that the goal of training a software engineering specialist is to form a stable professional competence, which is characterized by both a sufficient level of knowledge, abilities, skills and the necessary level of development of special abilities that ensure the successful solution of problems arising in professional activities at a high pace of development of this area [31, p. 7]. The main activity of such specialist is a design and constructive work in "a cognitive-virtual environment aimed at creating objects as entities that automatically support certain phenomena" [31, p. 22].

The higher education standard in the specialty 121 "Software Engineering" for the first (bachelor's) level of higher education defines the general goal of studying as "training specialists who are able to set and solve problems associated with the development, maintenance and quality assurance of software" [36, p. 5]. The programmatic result of such training is the building of the integral competence of the graduate, namely the ability to solve complex specialized tasks or practical problems of software engineering, characterized by the complexity and uncertainty of the conditions, using theories and methods of information technology [36, p. 6]. This graduate characteristic corresponds to features of the specialist prepared for the sustainable support of innovations in a specific subject field through his own activities to create an innovative product [31, p. 30].

Nail K. Nuriev defines that the persistent professional competence ensures the efficient activities of a specialist in solving professional problems at high rates of development of the activity field [31, p. 55]. According to this interpretation, the integral competence of a specialist in software engineering should be built to obtain the properties of sustainability (sustainable development). Nail K. Nuriev proposes to design a professional training system aimed at its formation, according to such methodological approaches as technical-technological, object-oriented, ontological and acmeological. The last two approaches aimed at the system knowledge formation along with intersubject communications and professional skills in solving problems in the software engineering field with a person

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steady direction to achieve the professionalism heights [31, p. 8].

Nail K. Nuriev defines the technology of training activities in the software engineering field as a specially designed for an educational purpose simulation model of the technology of professional activities in the software engineering field [31, p. 196]. Nailia Kh. Valeeva points out that such educational and professional activities will be efficient, in particular, in the context of its gradual formation, reliance on a context-personal approach, the creation and development of information and educational environment aimed at increasing students' motivation to learn and activating the process of building professional competencies [53, p. 4-5].

Olga P. Iurkovetc refers gnostic, operational-algorithmic, technological and team competencies to professional competencies of the junior specialist [18, p. 13]. They form a certain subset of the competencies of the bachelor in software engineering [36, p. 6-7] – general and special (professional, subject) competencies.

2 Sustainable competencies of software engineer

2.1 Ability for abstract thinking, analysis and synthesis

Sanjay Goel includes analysis / methodological skills to the critical competencies of a Software Engineering Specialist [13, p. 37]. Richard T. Turley and James M. Bieman highlight thinking among software engineering competencies [51, p. 25] (according to Sanjay Goel clarification – algorithmic and structural [13, p. 48]). The authors emphasize that "the observed development process was not linear: designers operated simultaneously at various levels of abstraction and detail" [51, p. 35]. Sanjay Goel indicates the following components of such thinking: reasoning and critical thinking (ability to question, validate, and correct the purpose, problem, assumptions, perspectives, methods, evidence, inference, reliability, relevance, criteria, and consequences); analytical skills; listening skills; quality consciousness and pursuit of excellence; constructive criticism; research skills (methods of mathematical research, engineering research, design research, and social science research); reflection and meta-cognition; self-acceptance, self-regulation, self-awareness, self-improvement; sensitivity towards global, societal, environmental, moral, and ethical issues, and sustainability; entrepreneurship, sense of mission, perseverance, commitment, self motivation, dedication; adaptability, flexibility, open-mindedness, and ability to multi-task [13, p. 131].

Among the factors of success of Software Engineering specialists, the authors [41] distinguish such components of competence as the level of abstract thinking (theoretical analysis), analytical thinking, the ability to concentrate, expressiveness (the ability to express one's own ideas to others in acceptable forms) and the ability to visualize (thought modelling, determination ways to "observe the invisible") [41, p. 167].

2.2 Ability to apply knowledge in practical situations

Sanjay Goel adds the ability to apply knowledge in the list of decisive competences of a Software Engineering Specialist [13, p. 57]. According to Vladyslav S. Kruhlyk, this competency is a component of the personal and professional competence of a Software Engineering specialist, which he associates with the lability of thought processes: "this property is important in the professional activities of programmers when there is often a need to complete their tasks quickly, ability to abstract, identify the main features in the subject of perception, switching from one work task to another without loss of productivity" [24, p. 149].

2.3 Ability to communicate in native language

"The defining feature of a successful programmer is the level of his verbal abilities – the higher it is, the more success the programmer will achieve in programming" [14, p. 12]. Marina S. Orlova submits that the professional communicative qualities of programmers include the ability to purposefully organize communication, listen to the opinions of others with understanding, the ability to discuss acute problems in a positive emotional mood and to mediate between conflicting individuals, the ability to correctly respond to various communication situations in the course of professional activity [33, p. 8] and other components professional communicative competence as the ability to build an effective focused professional interaction on the basis of a body of knowledge, abilities, and skills in the sphere of communication [33, p. 11]. The author distinguishes two goals of teaching programming in the process of professional training: 1) mastering students a culture of thinking and the ability to present the results of their professional activities in writing and orally; 2) professional training, which determines the need for the student to accumulate experience in professional activities [33, p. 9].

Maiia V. Bernavskaia points out that the professional communicative competence of Software Engineering specialists should take into account the peculiarities of their professional communication related to communication via ECM: "since the industry of professional activity of software engineers is in the field of collection, processing, storage, transmission and methods of obtaining information, the organization of its transmission channels, modern means and methods of information protection in global and local networks, it can be said that all types of professional activities have a communicative overtones" [2, p. 3]. The author includes three aspects in the structure of professional communicative competence: cognitive (knowledge of the means and methods of communication), interactive (organization and establishment of the process of mutual exchange of information) and perceptive (knowledge of

the regulatory and technical features of the interaction between man and technology) [2, p. 11].

Ravzhaa Narantcetceg identifies the information and communication competence of foreign students as a component of the professional competence of Software Engineering specialists and indicates the following principles for setting up specialized terminology in bilingual education: the principle of using semantic and structural calques in translation; the principle of reliance on the native language to create new terms in the setup and enrichment of terminology; the principle of terminologisation of non-terms; the principle of combining the achievements of various industries for creation a joint terminology [38, p. 9-10].

Japan Accreditation Board for Engineering Education distinguishes communication skills including logical writing, presentation and debating among the common criteria for accreditation of professional education programs applicable in the years 2019 and among the key general engineering competencies in later years [19, p. 1]. Sanjay Goel analyzes the results of a survey of employers, including communication skills of the 10 most important engineering and general professional competencies of a Software Engineering specialist [13, p. 37], indicates that "the communication needs of software developers are very different from the communications needs of sales or marketing professionals. ... It mainly involves listening with understanding and empathy. The communication competence of software developers encompasses the need to communicate their difficulties and vision to their clients, management, colleagues, and end-users, and also preparing technical documentation, and also end-user documentation. One needs to keep himself in the shoes of the end-user to give a useful product. Communication encourages the exchange of ideas and project related knowledge among the people engaged in the project: clients, managers, and developers" [13, p. 106]. Communication competency is connected with ability to work in teams, listening skills, "be the customer" mentality, persuasion, negotiation, consensus building, and conflict resolution skills, mentoring, coaching, and training skills, organizational skills.

2.4 Ability to communicate in a foreign language

Sanjay Goel analyzes the results of a survey of Indian employers and includes English language skills in the list of 10 most important engineering and general professional competencies of a Software Engineering specialist [13, p. 37]. It should be noted that English is one of the two official languages and the language of international communication in India.

Maiia V. Bernavskaia points out that in the system of training competitive in the labour market specialists, the role of a foreign language significantly increases, knowledge of which becomes an integral part of the professional competence of Software Engineering specialists, and emphasizes the clearly expressed English-language nature of professional communication: "This fact is confirmed by that all algorithmic programming languages that are a means of a programmer's work, based on linguistic constructions of the English language, the speed of memorizing and interpreting programming language constructs depends on the level of proficiency in these constructions. In addition, the proficient in English programmer is improving the reaction of communication with the operating system during the interactive dialogue, the problem of setting up and editing the program and many other professional aspects of the activities of the software engineer is solved much faster. Today … the programmer's willingness to communicate in a foreign language is not only welcomed but also becomes an integral attribute of his professionalism" [2, p. 3]. Svetlana V. Diudiakova and Larisa M. Gorina point out that ensuring the graduate's competitiveness in the labour market directly depends on his knowledge of the English-speaking thesaurus in special disciplines, and highlight the combination of relevant skills needed in the professional work of future programmers: in the first place is the ability to read English texts (fluent effective viewing of authentic professional material for understanding its essence, quick detection of the necessary information, competent foreign language annotation, discussion of professionally obtained information), in the second – the ability to write in English (reviewing, expressing one's own motivated opinion on a specific professional issue, correctly writing foreign professional documentation), in the third – the ability to understand English by ear (quickly highlight the logic of authentic professional information, critical perception, analysis, effective response even in stressful situations), and in fourth place – the ability to pronounce English words (conducting presentations about the prepared perspective and critical projects using multimedia technologies, conducting effective foreign language spontaneous discourse on professional issues in compliance with the cross-cultural standards) [9, p. 3, 10, 11; 14, p. 13].

Larisa M. Gorina found that in relation to foreign language skills and abilities in professional competence, which are formed in student programmers due to using English language, the general part of the "professional competence" concept is structured into the following components: professional foreign language (using a professional English-language component as an integral unit of professional competence); professional foreign language communicative (experience at high quality and logical solving multi-purpose tasks about professional foreign language functionality); professional psychological (confirmed deterministic level of foreign language proficiency, due to requirements made by employers, cause by high variability of the professional environment, based on the stability, confidence and stress resistance of programmers in the process of foreign language professional activities, even in unforeseen situations). The author proposes a technology for the formation of a set of foreign language skills and abilities in the professional competence of student programmers (developed skills to logically, constructively and quickly perform multi-purpose tasks,

carry out effective selection, optimal coherence in organizing an authentic professional material competently orally and in writing, fluently use English-speaking structures in variable sentences on professional topics, independently control the specifics of English pronunciation, intonation, the pace of speaking, the variability of the style spectra used when presenting professional information which aimed at achieving the stated goals and positive results), focused on the logical, consistent introduction of foreign language material on professionally-oriented topics, which minimizes the time spent (in the implementation of promising critical computer science projects using multimedia resources) [14].

Inna V. Chirva formulated the main methodological requirements for computer programs with differentiated training for future English-speaking programmers: computer educational program in English should be an integrated part of the language discipline, organically connected with its structure and content, as well as with the applied methodology, creating an integral whole and serving as a means of supporting it; focus on the formation of skills and abilities of English dialogical speech; compliance with the principle of communicativeness; creation of favourable conditions for each student to master educational material in accordance with the level of their knowledge and abilities; the organization of branched feedback in order to manage the educational work of students in the process of passing each individual trajectory of learning; professional orientation of the program content; inclusion in the training content of the regional geographical aspect; the use of multimedia tools to create a controlled language environment; warnings of common mistakes, etc. [6].

2.5 Ability to learn and acquire up-to-date knowledge

Japan Accreditation Board for Engineering Education distinguishes an ability to learn independently and continuously among the common criteria for accreditation of professional education programs applicable in the years 2019 and among the key general engineering competencies in later years [19, p. 1]. According to Vladyslav S. Kruhlyk, this competency is a component of the personal professional competence of a Software Engineering specialist, which he associates with the self-learning ability, namely focused, autonomous educational and cognitive activities of future software engineers aimed at independently acquiring and applying knowledge in the field: "self-learning ability implies understanding by future software engineers of the importance of updating professional information and implementing actions to monitor new products in the professional sphere, systematization and generalization of new knowledge in the IT field" [24, p. 150].

2.6 Ability to search, process and analyze information from various sources

In the structure of the professional competencies of a competitive specialist, Irina G. Frizen [11] identifies information competence based on the subject's ability to efficiently search, use and evaluate information. According to Larisa M. Gorina, the basis for the formation of this competency is the communicative component of professional competency [14, p. 13], which Mariia M. Gladysheva associates with the formation of research skills through skill assignments: navigate in a variety of software tools while searching for new information; determine the most effective methods of collecting and processing information; develop your own algorithm to solve the problem; prove the program correctness; evaluate the efficiency of the created software product; plan an experiment and process experimental data. To do this, students analyze diploma works that contain a description and results of the experiment, analysis of abstracts, course works, scientific articles, reports, etc. [12, p. 16].

Liudmila B. Tarenko identifies the analytical skills of future IT professionals, the content of which is combinations of special intellectual and analytical-synthetic processes aimed at achieving qualitative personality changes and contribute to the growth of professional skills of a specialist [49, p. 7]. The conditions for the successful formation of the analytical skills of future specialists are the use of developing tasks, the students' independent work focuses on research activities, personality-oriented interaction between teachers and students based on the project method [49, p. 8]. The author refers cognitive skills (ability to operate with signs and symbols; ability to use generalized structures; ability to build dynamic models of the problem-solving process) and metacognitive skills that carry out self-regulation (the breadth of transfer of mental actions to new conditions; readiness for planning; ability to set new goals and put forward new ideas; ability to develop and use original ways of solving problems in various situations, including non-standard ones; ability to identify the difficulties of cognitive activities; ability and skills of self-control) to the analytical skills structure.

Dzhamilia A. Mustafina refers the professional-personal competencies to the structure of the competitiveness of a Software Engineering specialist (competency that ensures the efficiency of his professional activities and behaviours in a competitive environment): values and meanings of professional activities; knowledge, skills and abilities; decision-making experience in market situations; information competence, namely the ability to find information, which ensures the effective decision-making; engineering thinking, which includes a reflection of the quality of the process and the result of design and construction activities from the standpoint of market requirements; social competencies such as legal and communicative [29, p. 8-9].

Viktor P. Agaltcov considers the tetrad "knowledge – targeted search – analysis and synthesis of search results

– experimental verification of the found solution" [1, p. 11] as the basis for an interactive approach to training Software Engineering specialists.

2.7 Ability to work in a team

This competency is closely related to the professional communicative competence of software engineering specialist, the basis of which is: a) communicative knowledge – knowledge about the types and phases, methods and techniques of communication, their capabilities and limitations, as well as knowledge about yourself (about the degree of development of your own various communicative skills, the efficiency of the application and own execution of effective communication methods) and about other people (knowledge about the degree of efficiency of certain methods regarding various people and situations); b) communicative skills – mastery of psychological and practical activity systems that allow you to purposefully regulate the subject's communicative activities on the basis of his communicative knowledge and abilities, for example, ability to form a message text in an adequate form, speech skills, ability to harmonize external and internal manifestations, ability receive feedback, ability to overcome various communication barriers, etc. [33, p. 12]. Marina S. Orlova points out that the development of professional communicative competence is facilitated by the implementation of complex group projects, which are also a means of training teamwork skills, ability to communicate with colleagues, listen to the opinions of others, defend one's point of view, competently present the project and colleagues' contribution in it [33, p. 18].

Sanjay Goel [13, p. 37, 57] and Japan Accreditation Board for Engineering Education include an ability to work in a team in the list of critical general engineering competencies of a Software Engineering specialist [19, p. 2]. As noted by Sanjay Goel, "as compared to the other kinds of engineering industries, the software industry places a much deeper level emphasis on group work. Large multi-locational, multi-cultural global teams concurrently work in different parts of the world to meet the requirements of clients of varied cultural backgrounds. The majority of an engineer's time in the software industry is spent working with other programmers. The nature of group work among software engineers is not limited to process-centered coordination" [13, p. 70].

2.8 Ability to act on the basis of ethical considerations

Liudmila N. Kanishcheva points to the need for developing personal-competency experience of future Software Engineering specialists, which reflects the peculiarities of humanitarian-oriented professional activities based on the principles of the absolute value of human life and human personality, people's safety, ethics and social ecology [21, p. 6-7].

Elena N. Ishakova includes a moral component in the structure of humanitarian knowledge of Software Engineering specialists that contains the most general principles of activity culture in general and professional in particular, which provide reliability and predictability of actions [17, p. 11].

Japan Accreditation Board for Engineering Education in criteria for accreditation of computing & IT-related education programs at bachelor level among key competencies puts in second place ability of understanding of effects and impact of professional activities on society and nature, and of professionals' social responsibility: "This item indicates professional ethics such as, relationship among technologies, society and nature, and understanding of professionals' social responsibility. Professional ethics of the ICT professionals are not so much different from professionals of the other fields however; sufficient understanding on issues related to copyright shall be particularly considered as ICT-oriented. As for the technologies, safety is critically important issue however in terms of information technology, "Information Security" is specific additional concern which requires sufficient understand." [20, p. 6].

Sanjay Goel offers the following principles of professional ethics for a Software Engineering Specialist [13, p. 52-53]:

1. The specialist must fulfil his professional duties, putting safety, health and welfare of the public in the first place.
2. The specialist must undertake technological tasks for others only if qualified by training or experience.
3. The specialist must act for each employer or client as faithful agents or trustees.
4. The specialist must issue public statements only in an objective and truthful manner.
5. The specialist must avoid improper solicitation of professional assignments.
6. The specialist shall continue to develop relevant skill, knowledge, and expertise throughout their careers and shall actively assist and encourage those under their direction to do likewise.
7. The specialist must promote an ethical approach among colleagues.
8. The specialist must continuously strive for quality, excellence, and adherence to highest professional standards.

Edward J. O'Boyle [32] proposed the six-step ethical decision-making process for computing professionals. The first stage involves moral perception and personal knowledge of the moral good, which depends on the awareness of the ethical problem and personal responsibility for it. The second stage is moral discernment and personal ability to think logically, which allows a person to clearly define an ethical problem. The third stage is moral resolution and personal ability to think analytically for formulating an individual position on the stated problem, acceptable to one's own conscience. The fourth stage is a moral assessment and personal ability to assess one's freedom (IT specialists must know about new developments, especially in the context of technology history, in order to properly handle new freedoms). The fifth stage concerns moral decision and personal knowledge of one's duties. The

final step is moral action and personal willingness to follow one's intellect [32, p. 272-274].

2.9 Commitment to preserving the environment

Valentina A. Danilenkova understands the environmental competence of future engineers as the creation of a system of knowledge, attitudes and beliefs necessary for general orientation in an environmental situation, prevention or limitation of environmental risk activities aimed at understanding the moral responsibility of a person for the state of the environment in all types of engineering activities [8].

Sanjay Goel includes (i) awareness of environmental issues, and (ii) sensitivity towards socio-economic aspects for sustainable technological development to the general professional competencies of a Software Engineering specialist [13, p. 36]. In the list of professional competencies for Software Engineering specialists at the University of Victoria, the group of competencies related to professional practice is consistent with the standards and ethical code of the Association of Professional Engineers and Geologists of British Columbia. The first professional competence of a Software Engineering specialist is to ensure the safety, health and well-being of the population, environmental protection and the promotion of health and safety in the workplace [7].

Mario Gerardo Piattini Velthuis and Coral Calero Muñoz [4] indicate that ICT, "on the one hand, it helps organisations to tackle environmental issues (using video conferences, dematerialisation, more efficient processes, etc.); on the other hand, technology itself is often responsible for major environmental degradation (amounts of energy consumed by the engineering processes used to manufacture products). This dual aspect of technology means that organisations also face two challenges: they need to have more sustainable processes and they must produce products that contribute to a more sustainable society" [5, p. 4]. Initiatives that promote respect for the environment through ICT, IT, software, etc., are called environmental or Green ICT/IT/Software [4, p. 5], linked with the concept of sustainable development.

2.10 Ability to act in a socially responsible and conscious manner

Speaking about the future foreign programmer's information and communication professional environment, Iuliia A. Bushmanova defines the community of professional open-source software developers as subjects of such an environment, namely "social groups that are formed by highly skilled programmers from around the world who create software on a voluntary basis" [3, p. 13].

Liudmila N. Kanishcheva also points out the socially-oriented nature of software projects, which requires future Software Engineering specialists to develop skills to identify the main consequences that the project may have for society, public morality, human health and environmental safety [21, p. 7-8]. Dmytro E. Schedrolosev identifies a socially significant value attitude to events, people and himself among the components of professional competence of a future software engineer [40].

Japan Accreditation Board for Engineering Education among common criteria for accreditation of professional education programs applicable in the years 2019 and later among key general engineering competencies puts an ability of understanding of effects and impacts of professional activities to the society and to the nature of, and understanding of professionals' social contributions and responsibilities [19, p. 1].

Among the structural components of the competitiveness of a Software Engineering specialist, Dzhamilia A. Mustafina distinguishes responsibility, which manifests itself in the moral qualities and humanitarian expertise of technical projects, and social competencies: legal (knowledge of the guidance and regulatory materials governing the development of algorithms and programs and the use of computer technology in processing information, the fundamentals of labour legislation, labour protection rules and norms, ways to solve legal problems) and also communicative which provides the ability to conduct discussions in the professional (formal) language [29, p. 14].

David Lorge Parnas [35] distinguishes the personal, social, and professional responsibility of a Software Engineering Specialist:

- personal responsibilities are general obligations towards other individuals; most are shared by all persons (e.g. honesty, concern for others);
- social responsibilities are responsibilities towards society as a whole: "We have a debt to repay because society has supported us when we needed it" (e.g. environmental activism, peace activism, national defence);
- professional responsibilities are additional responsibilities shared by members of a particular profession.

2.11 Ability to realize the rights and obligations as a member of society, to recognize the civil society values and the need for its sustainable development, the rule of law, human rights and freedoms

Characterizing the social responsibility of software development, Diomidis Spinellis indicates that "... a software developer, for better or worse ... building the fabric of our society, tomorrow's world. ... Many of the things you do have ethical, social, and political implications. ... On a larger scale, new digital platforms, products, and services might disrupt the livelihood or working conditions of millions. Also, machine-learning algorithms might promote discrimination or produce invalid results in ways that are difficult to detect and analyze" [44, p. 4].

To build this competency, Diomidis Spinellis offers:

1) to study history, philosophy, political science, sociology, ethics and art;

2) to talk about the wider consequences of their own labor: "What will happen when your shiny prototype gets widely deployed or stops being maintained? Will your new web-based service disadvantage a particular minority? What if all the data you're gathering falls into the hands of organized crime or a totalitarian government? Is the cyberweapon you're developing more likely to be used for defense or for offensive actions and terrorism that can hurt countless civilians? What if criminals can gain control of the law-enforcement backdoor access you're providing? How will your new social-interaction feature affect children or families?" [44, p. 5];

3) to act responsibly: "Strive to design and implement the software you work on so that it becomes a force for good rather than evil. Don't work for organizations whose mission is intrinsically detrimental to society. If your organization develops software that will harm society, speak up. ... seek alternatives, deliberate, and think through your actions. ... By depriving evildoers of your talent, you contribute to everyone's well-being. ... Also, if you see that your organization develops harmful software, try ... argue that in the medium or long term, being socially responsible might benefit your organization. Or, you can come up with win–win options: software that's good for both your organization and society" [44, p. 6];

4) to teach others: "Modern software is mind-numbingly complex, and it often interacts with our world in subtle, unanticipated ways. As a software developer, you might understand these things ..., but your colleagues from other backgrounds and the public at large might not. Help by uncovering, explaining, and publicizing any issues... Discuss with your colleagues, post in social networks, write articles... As an educated professional, you have the duty to return to society part of the education it has endowed you with. And, if you're an educator, strive to include the topics in your lectures and the curriculum" [44, p. 6];

5) to communicate with others, establish social connections: "Engage with your professional societies to raise awareness of these issues [social responsibility] and develop defence and support mechanisms... Mingle with people outside your (probably privileged) circle... Write free software that could help our world become a better place. Work with think tanks, civil-society organizations, and political parties to draft and promote sensible policies. Volunteer for office and, it should go without saying, get out and vote" [44, p. 6].

Thus, the last two competencies are not just interrelated: in fact, it is one competency, which is confirmed by the international standard ISO 26000: 2010 "Guidance on social responsibility", which links corporate social responsibility and sustainable development of society. This International Standard is intended to assist organizations in contributing to sustainable development – development that meets the needs of the present without compromising the ability of future generations to meet their own needs [16, p. 3]. Sustainable development is a combination of the goals of high quality of life, health and well-being with social justice and the Earth's ability to support life in all its diversity, with social, economic and environmental goals being interconnected and mutually supported [16, p. 4].

Therefore, corporate social responsibility can be defined through the responsibility of the organization for decisions and activities (products, services and processes) impact on society and environment through transparent and ethical behaviour, which contributes to sustainable development, including the health and well-being of society; takes into account the expectations of stakeholders; complies with the law and is consistent with international standards; integrated into the activities of the entire organization and is used in its relationships (the activities of the organization within its sphere of influence) [16, p. 3].

The Software Engineering Specialist, who works on the basis of the relevant code of ethics, already contributes significantly to the preservation of values and the sustainable development of civil society. Standard ISO 26000: 2010 includes ethical behaviour and a commitment to preserving the environment towards social responsibility, proposing organizations to comply with the following principles [16, p. 9-12]:

1. *Accountability* for influencing society, the economy and environment, accepting criticism and responding to it.
2. *Transparency* in decisions and activities that affect society and the environment.
3. *Ethical behaviour* based on values such as honesty, fairness and integrity, caring for people, animals and the environment.
4. *Respect for stakeholder interests*.
5. *Respect for the rule of law*: equality before the law – not a single individual and organization is above the law, and the government is also subject to the law.
6. *Respect for international norms of behaviour* so that in cases where the legislation of the country does not provide adequate environmental and social restrictions, the organization adheres to at least the minimum international standards.
7. *Respect for human rights* (civil, political, economic, social, cultural, labour), recognition of their importance and universality, prevention of discrimination.

The Standard defines a number of issues related to various aspects of socially responsible organizational management:

– *labour relations:* working conditions, social protection, social dialogue, labour protection and safety at the workplace, human development and training at the workplace;

– *environment:* pollution prevention, sustainable resource use, climate change mitigation and adaptation, protection and recovering the environment;

– *fair business practices:* fight against corruption, responsible political involvement, fair competition, promotion of social responsibility within the sphere of influence, respect for property rights;

– *consumer issues:* fair practices in marketing, providing information and contracting, protecting the health and safety of consumers, continuous consumption, data protection and consumer privacy, access to essential services, education and awareness-raising;

– *participation in communities life and their development* through education and culture, employment and skills development, technology development, wealth and income creation, health and social investments.

Considering the formation of the social and professional activities of the personality of a student of a technical institution of higher education in the context of civil society reform, Tatiana V. Solonshchikova highlights personality traits corresponding to competencies [43, p. 16-17]:
- social and civic personality traits (social and civic activity and responsibility, patriotism, tolerance, etc.);
- professionally oriented personality traits (love for the profession, activity in the professional sphere, initiative, self-confidence as a professional, communicability);
- professional and labour personality traits (conscientiousness, responsibility, ability to fulfil commitments, professional duty, personal leadership, etc.);
- professional and moral personality traits (humanism, collectivism, justice, goodwill, honesty, integrity, tact, intelligence);
- general cultural personality traits (cognitive activity and independence, aesthetic culture, culture of appearance, language, breadth of interests and spiritual needs, creativity, etc.).

These qualities are the basis for the building of the following competence.

2.12 Ability to preserve and enhance the moral, cultural, scientific values and society achievements based on an understanding of the history and patterns of the subject area development, its place in the general system of knowledge about nature and society and in the development of society, equipment's and technology, to use various types and forms of physical activity for active recreation and healthy lifestyle

Japan Accreditation Board for Engineering Education in criteria for accreditation of computing & IT-related education programs at bachelor level among key competencies puts at the first place ability of multidimensional thinking with knowledge from global perspective: "this item indicates education and ability to think required for the autonomous professionals who engage to build sustainable society, to change it from materialistic to one put emphasis on spiritual values and who are able to perform internationally" [20, p. 6].

Characterizing the subjective health status of IT professionals (including Software Engineering specialists), Maki Tominaga, Takashi Asakura, and Tsuyoshi Akiyama found that quantitative and qualitative workload was the most important predictor of both psychological disorders and cumulative symptoms of fatigue as subjective variables health conditions. Career growth and future uncertainty among other macro stresses were the most important predictors not only for staff turnover but also for the subjective health state of IT specialists [50, p. 478-479]. "Therefore, health management measures for computer professionals should include technical education corresponding to the accelerating technological innovation, provision of opportunities of personnel training with consideration given to various career paths such as management and related departments, and the announcement of a policy of medium- to long-term career development" [50, p. 479]. The results of this study confirm the concept of "organizational health", according to which organizational characteristics (such as management practices, organizational culture/climate, and organizational values) are important factors affecting "organizational health" such as workers' health/satisfaction and performance [50, p. 483].

Characterizing the physical and mental health of Software Engineering specialists [30], Mariko Nishikitani, Mutsuhiro Nakao, Kanae Karita, Kyoko Nomura and Eiji Yano indicate that the specific nature of their activities creates great psychophysiological stresses on the body (vision, hearing, muscles of the arms and hands, legs and torso), so they feel discomfort and decreased performance. Aleksei I. Kardashevskii points out that they need to learn how to organize their own behaviour, paying attention to professional self-preservation, the program of which may include: readiness for continuous self-improvement; personal responsibility for their own health; developing adequate means to overcome undesirable conditions; mastering the methods of mental self-regulation and normalizing the level of performance, eliminating the consequences of professional fatigue; prevention of possible personal deformations in your profession; excluding self-destructive behavioural strategies from your life [22, p. 3]. The author refers professional health-saving competencies to the ability in conducting short breaks for exercises to relieve eye fatigue in the process of professional activities: the ability to quickly, directly at the workplace, conduct periodic procedures for unloading the muscles of the hands, arms and fingers; ability to carry out exercises in a timely manner to relieve the fatigue of the back and legs muscles.

Galina E. Siakina points out that physical activity is a natural and specially organized person activity ensures his successful physical and mental development: "Properly selected and optimally planned physical activities contribute to maintaining a high functional level of all systems, provide sufficient general and special workability, make human life more economical, prevent the development of many pathological processes in the body. Physical activity promotes the assimilation of information coming from the external environment through sensory systems. ... Physical exercise is a means of outdoor activity in educational activities. Muscle movements create a huge number of nerve impulses, improving blood circulation in the brain. Available physical exertion has a positive effect on mental activity." [39, p. 10]

Tatiana E. Veselkina indicates the following main factors contributing to the increase in the efficiency of students independent physical exercises: a) the formation of students' self-monitoring skills for the health and the dynamics of the physical qualities development at the

initial stages of training in institutions of higher education; b) the creation of interactive methods of interaction between teacher and student using modern information technologies that allow teachers to monitor and actively influence the quality and safety of conducting independent classes [54, p. 19-20].

Aivar K. Khashkhanok points out that outdoor activity has a positive effect on health and well-being, mood and speed of recovery after work, on the attitude to physical activity and physical education, helps to increase working capacity and build healthy lifestyle skills [23, p. 3]. Leisure activities using physical exercises more than all other types of recreational activities correspond to the characteristics of a healthy lifestyle and allow you to achieve the necessary volumes of physical activity [23, p. 26].

2.13 Ability to apply fundamental and interdisciplinary knowledge to successfully solve software engineering problems

Analyzing the results of a survey of employers, Sanjay Goel puts problem-solving skills in the first place from 10 most important engineering and general professional competencies Software Engineering specialist [13, p. 37], and considers them as the key skills. The author includes knowledge of the strategy for solving problems and conceptual knowledge to the knowledge that relates to this competence.

Japan Accreditation Board for Engineering Education, in common criteria for accreditation of professional education programs applicable in the year 2019 and later, puts in third place among key general engineering competencies knowledge of mathematics, natural science and information technology, and ability to apply [19, p. 1]. The criteria for accreditation of undergraduate IT programs specify that knowledge of mathematics including discrete mathematics, probability and statistics and natural sciences required in the related professional fields [20, p. 7].

On the basis of a professiographic and contextual approach to building a model for training programmers, Svetlana A. Gudkova [15] showed the importance of a foreign language not only as a means of communication in the professional sphere of a programmer's activities but also its role in constructing of formal languages constructions (based on the identity of morphological, syntactic, semantic constructions of the English language and programming languages), which is an integral attribute of the professional competence of programmers. The concept of "language" is considered by the author in the meanings: language as a sign system; language as a formal system (machine language, translators, etc.); language as a means of communication of "subject-subject", "object-object" and "subject-object" type; language as a high-level programming language; language as a means of data processing of information systems (SQL).

Mariia S. Lezhneva notes that the qualification of an IT specialist depends on his ability to interprofessional interaction with representatives of other specialities for carrying out integrated projects, which determine the success of the country's economic development: "the main directions of training IT specialists ... should be: fundamental mathematical training; development of professional culture; readiness for continuous cognitive activity, both within the profession and beyond; formation of the motivational basis of professional interaction" [25, p. 12].

Minevali M. Minshin defines the professional and applied mathematical competence of software developers as a systematic personality formation of an engineer, which contains the capabilities of the thinking algorithm, the willingness to creatively use mathematical tools for solving engineering and practical problems in the field of professional activity and motivational need for continuous mathematical self-study and self-development [28, p. 7]. Characterizing the competent structure of specialist training results, the author determines the competencies necessary for successfully solving software engineering problems, including the ability to use linear algebra to describe objects and systems; generalization, perception of information, goal setting and choice of solutions to IT problems; analysis of professional and socially significant problems and processes associated with the computerization of production; self-development and improving the quality of automated systems design results; identification and development of algorithms; application of analogies and generalizations; application of modern programming technologies; database optimization based on mathematical criteria; the use of mathematical logic in the development of programs; the use of various calculus systems, coding theory and error correction codes, as well as the development of new software products based on mathematical models.

Considering the use of mathematical methods in the professional activities of Software Engineering specialist, Elena R. Dubenetckaia suggests considering the use of mathematical statistics methods for calculating indicators of statistical characteristics of industry information, mathematical modelling methods for constructing information-logical models of developed software products, methods of mathematical logic for computing logical expressions when developing sector-specific software, and others [10, p. 9-10]. The author defines the following competencies for the application of mathematical methods in professional activities:

– the ability to choose mathematical methods for performing professional tasks (knowledge of the basic concepts of mathematical methods and the features of their use in professional activities, the ability to correlate the mathematical method to the data of the solving professional task and identify the capabilities of the software product that ensure its implementation, practical experience in the implementation of mentioned knowledge and skills);

– willingness to apply mathematical methods to solve professional problems (knowledge of the features of the application of mathematical statistics, mathematical modelling, mathematical logic and numerical methods; the ability to apply: mathematical statistics methods for statistical analysis of industry information and

calculation of indicators of its statistical characteristics, processing of measurement data and monitoring of operating parameters industry-specific equipment, calculation of quality characteristics of a sector-specific software product, calculating the cost, timing and risks of project operations; mathematical modelling methods for constructing information-logical and graphical models, creating dynamic and interactive content of industry-specific information resources; numerical methods for performing various computational operations in the processing of industry information; mathematical logic methods for calculating logical expressions in the development of industry-specific software, making a logical operation when determining the risks in project activities; practical experience in applying the specified knowledge and skills to solve professional problems);
– willingness to use software products for the application of mathematical methods while performing professional tasks (knowledge of the capabilities of software products and the features of their implementation in the process of applying mathematical methods, the ability to: collect, analyze and process industry information; computational activities based on the calculation of the quality characteristics of an industry-oriented software product, cost, terms and risks of project operations; modelling and visualization of information objects on the screen; building graphs and charts that describe various indicators; developing sector-specific software and information resources; practical experience in applying the specified knowledge and skills to solve professional problems) [10, p. 16-17].

Svitlana I. Tyshchenko identifies the conditions under which the integration of mathematical and special disciplines content will increase the efficiency of professional training of future Software Engineering specialists: 1) an integrative approach to the study of mathematical and special disciplines; 2) strengthening the professional-applied nature of mathematical knowledge and skills while studying special disciplines; 3) coordination of the study of the selected content of mathematics material in the classroom and extracurricular activities with the aim of knowledge creation in special disciplines; 4) intensification of independent educational activities by applying a methodically balanced system of adjusting professionally directed knowledge in mathematics [52].

Elena N. Ishakova considers the blocks of humanitarian knowledge that a programmer needs to successfully perform professional functions at all stages of engineering: 1) at the stage of strategic planning and analysis of software requirements, humanitarian knowledge allows a software engineer to understand the social order, that is, social and production technical need for this software tool, based on the assessment of social, economic, environmental, ergonomic parameters of the software system and the consequences of its implementation; 2) design, implementation, testing and debugging of the software system is carried out at the stage of creating innovative software. The efficient implementation of these processes requires updating the following components of humanitarian knowledge: scientific search methodology, programming methodology, information engineering, psychology of thinking and perception, structural and applied linguistics, cognitive science (knowledge engineering), system analysis, decision theory, etc. The stage of software maintenance and operation includes user service and the elimination of possible minor errors. At this stage humanitarian knowledge allows the software engineer to evaluate the possible savings of material, human, financial resources, their optimization, take into account the physiological and hygienic characteristics of users' labour, legal and ethical aspects of the protection of software products and databases [17, p. 11-12].

2.14 Ability to evaluate and take into account economic, social, technological and environmental factors affecting the sphere of professional activity

Liudmila N. Kanishcheva points out that forecasting and assessing the consequences of software projects implementation, impact on environmental safety, society, public morality, and human security actualize the problem of developing experience of future Software Engineering specialists in the humanitarian expertise of design and technical solutions, which is aimed at identifying compliance proposed solution to social, moral, environmental, cultural, aesthetic and other humanitarian standards [21, p. 3]. The humanitarian expertise of the project includes three main blocks: 1) the economic block: the relevance of it for the modern economy development; scientific equipment of the project, compliance with norms and standards in terms of technical performance; the integrity of the project, involves goal coordination, project objectives, implementation plan, the availability and rational selection of necessary resources; 2) the social block: environmental friendliness of the project; social security (compliance with legal norms); humanitarian orientation (absolute value and priority of human life and health, adherence to moral standards) 3) aesthetic block: creativity, flexibility and dynamism of the developed project; aesthetic appeal [21, p. 23].

According to Galina V. Prozorova, the formation of bachelors professional competencies taking into account the industry specifics of the region's enterprises is a process of "interconnected mastery of professional knowledge, generalized methods, the experience of professional activities and the development of a positive motivational-value attitude to professional activity, based on differentiation and complementarity of the basic training and preparation for the performance of professional tasks in a specific area of economy, relevant for the region" [37, p. 9-10]. The author proposes to orient the educational programs of bachelor training to sector-specifics enterprises in the region: 1) determining professional tasks that require special knowledge and skills in a specific field of activity (economic sector or knowledge sector); 2) clarification of the content of the identified professional tasks at the sector-specific enterprises, relevant for the region; 3) the definition of

special knowledge and skills necessary to perform the identified professional tasks at the enterprises of the region, as components of professional competencies; 4) the inclusion of students in educational activities for the development of generalized methods for performing professional tasks specific to regional enterprises, through the development of a system of multilevel educational and professional tasks [37, p. 10, 15]. With this approach, graduates are more motivated to find employment in the region, which contributes to its socio-economic development.

Japan Accreditation Board for Engineering Education in criteria for accreditation of computing & IT-related education programs at bachelor level distinguishes the design ability to respond to requirements of the society by utilizing various sciences, technologies and information among key competencies. "This item expects comprehensive ability required to apply information science and technology to the problem-solving process. Therefore, it means "design ability to respond to requirements of the society by utilizing various information sciences and technologies". Design ability is composed of items such as problem analysis, modelization, extract and define requirements and design, implement and evaluate systems, processes, components and programs. ... Design ability in practice includes: conceptualize ideas; identify and formulate problems; comprehensively apply various disciplines and technologies; create ideas; identify issues from the view points of public health and safety, culture, economics, environment, ethics etc. and find solutions to the problem under these constraints; verify the results; demonstrate the ideas in drawings, sentences, equations, programs etc.; communicate with others; collaborate with others (team work); and continuously plan and implement as planned, and it is expected to perform all of those in a holistic manner" [20, p. 7-8].

2.15 Ability for lifelong learning

Dmytro E. Schedrolosev [40] distinguishes a readiness for creative work and constant self-education among the components of professional competence of a future software engineer.

Liudmyla A. Matviychuk points out that the efficiency of the future professional activities of software engineers is determined by the need to form a modern scientific worldview, focusing on continuous self-improvement. By professional knowledge of future software engineers, the author understands the existing step-by-step system of "theoretical and practical knowledge of the professional activity, the elements of which are interconnected and depend on the student's desire to achieve a high level of professionalism in the chosen field of activity and ensure career growth" [27].

Svitlana I. Tyshchenko revealed that the modern criterion for effective professional training of Software Engineering specialist is the ability to update knowledge and skills throughout his life in accordance with the constantly growing requirements for his competency characteristics [52].

Nina Y. Padalko defines the professional skills of the future programmer as a dynamic education, including a system of scientific knowledge about the organization of solving various problems; awareness of future professional activities; the quality of assimilation of an indicative labour perspective; a set of professional skills that provide a high level of self-organization of professional activities [34].

Japan Accreditation Board for Engineering Education distinguishes ability of independent and lifelong learning among key competencies in criteria for accreditation of computing & IT-related education programs at bachelor level [20, p. 3].

Recommendations for the development of curricula for Software Engineering bachelors define the competency of continuous professional development as the study of new models, methods and technologies, as soon as they appear, and the understanding of the need for such continuous professional development: "students should demonstrate the presence of self-motivation to study during the life-long training program. Students should be encouraged to search for new knowledge and evaluate their usefulness and relevance in the process of professional training" [42, p. 21].

Among the professional ethics principles of Software Engineering specialist highlighted by Sanjay Goel [13, p. 52-53] sixth (specialist shall continue to develop relevant skill, knowledge, and expertise throughout their careers and shall actively assist and encourage those under their direction to do likewise) and eighth (specialist has to continuously strive for quality, excellence, and adherence to highest professional standards) principles are directly related to the building of this competency.

Sanjay Goel points out that it is necessary for Software Engineering specialists to actively participate in lifelong learning for number of reasons [13, p. 146-147], in particular, the following:

– the applications domains are highly diverse and continuously evolving, consequently software developers have to continuously learn more about these domains, mostly through self-learning, and work experience often without any long term formal education in the concerned domains;

– various technological innovations and changing social trends are continuously and rapidly reshaping user expectations, understanding these continuously evolving expectations is very crucial for software developers;

– the development technology and platforms keep changing constantly often without proper documentation and examples, hence, the developers need to explore the useful enhancements and changes themselves again usually without much formal training;

– the developers usually have to understand other developers' work in order to extend, debug, maintain, integrate and/or re-engineer it;

– creation of "simple and idiot-proof system interfaces" requires them to be curious about how an average person approaches technology.

Conclusion

The proposed competency system of software engineering specialist aimed at creating sustainable professional competence is not complete – it primarily includes general professional competencies that specify such key competences for lifelong learning as literacy competence, multilingual competence, mathematical competence and competence in science, technology and engineering, personal, social and learning to learn competence, citizenship competence, cultural awareness and expression competence. They form the fundamental social and humanitarian core of training a software engineering specialist, modules are attached to it and reflect the current state of software technologies development.

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Quantification labour migration processes: systemization of the experience of foreign and domestic studies

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Abstract. The article made the attempt to systematize foreign and domestic research experiences on quantitative measurement of quality performance indicators work-migration processes. In particular, it analyses the possibility of harmonization of statistical accounting of labor migration, carried out by separate departmental systems to gather broad demographic information. As well as the features of the specialized and general sample surveys of the labour movement in the countries of ES and the post-soviet states. On the basis of the analysis of the necessity of the integration of economic, demographic and sociological approaches for full-scale analysis of the labour migration situation in the labour market. It is proved that sociological research work-migration processes more flexible, in comparison with the economic. And their use will allow to consider the impact on the adoption of the individual decisions on the labour movement of the whole complex of modern trends of development of society and economy. It is proposed to supplement recommendations A. Vorobyov, A. Grebenyuk, A. Topilin regarding the definition of the range of respondents, and social indicators included in the Toolkit of sample surveys of labour migration. The implementation of such methodological innovations will allow to solve the question of forecasting the dynamics work-migration processes.

1 Introduction

The regulation of labour migration processes, both external and internal, is one of the priorities of state institutions considering the need to control employment, income, living standards, and social well-being of society. Timely and reliable information is needed to assess the labour migration process. Developing strategies, forecasting dynamics and preventing negative effects are encompassed in this study.

The methodology for the study of labour migration involves the definition of the principles, structure, logic, forms, methods and means of scientific knowledge of the investigated phenomenon. The main problem of taking into account socio-economic indicators of movement of labour is the procedure for identifying a migrant worker. The definition of labour migration, set out in laws and other legal documents, should be clear, unambiguous and suitable for developing procedures for its quantitative analysis. However, in practice, representatives of state institutions do not always turn to sound scientific concepts. Therefore, the existing systems of statistical accounting differ not only in different countries, but even between individual departments of one state, since the latter can carry out accounting using absolutely different methods, choosing them depending on the specific tasks and functions of particular organizations. This state of affairs leads to a low level of data comparability or even complete absence thereof.

The difficulty of mainstreaming migrations, in comparison with vital statistics, is that you can be born and die only once, whereas in various kinds of labour movements a person can be involved many times. Thus, a labour migration statistics operates with events, facts of check-in/check-out activities, but not with quantitative indicators of the number of labour migrants, which significantly reduces the quality of mainstreaming, primarily due to the increase in the number of events that are recorded in comparison with the birth or death statistics. Another circumstance that causes problems in the collection of empirical information regarding labour migration is the presence of its irregular form, which is practically cannot be measured directly, and, accordingly, it is very difficult and sometimes impossible to determine its size and characteristics.

Labour migration in all countries, having mainly elusive nature, is one of the most difficult mainstreamed socio-economic phenomenon. The problem of absence of correct statistical information about various kinds of labour movement is felt acutely for both regions/donor countries and recipient countries. Consequently, nowadays in the context of globalization, the need for establishing and development of directions in statistical activity, related with the possibility of their mainstreaming, is actualized by labour flows increasing and also the emergence of new forms of labour movement.

The purpose of the research is to systematize the experience in quantitative studies of the dynamics trade magazine processes, as well as the conduct of specialized and General sample surveys of the labour movement in the countries of the European Union and post-Soviet

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States, for the development of methodological innovations, the implementation of which will optimize the social mechanisms of the state policy of regulation of labour migration.

The main source of information on migrations, including labour migration, is the state statistics, which provides current records of movements and a population census. Statistical study of labour migration processes should be based on the results of statistical monitoring of the labour activity of the population, which allow to estimate the determinants of labour migration formation, to identify significant/insignificant, clear/latent ones among them. Statistical accounting of international labour migration is a complex procedure that covers events registered simultaneously in two regions/countries (donor and recipient). The UN uses the model of accounting for international flows of migrants, which makes it possible to identify the links between leaving one country and arriving in another one. Of course, using such a model, it is necessary to take into consideration some theoretical assumptions that were made to construct it [4]. In particular, information support for the study of labour migration processes is defined as a scientifically based activity of stakeholders on collecting, fixing, processing, accumulating, storing and using information, messages and any other data in order to analyse labour migration processes, as well as develop state migration policy [5]. The system of information support for the analysis of labour migration includes official statistical data (current records, censuses and population registers, statistics on the crossing of state borders, etc.), as well as information received during specialized research studies conducted by academic institutions and other specialized sample survey organizations.

2 Brief literature review

A significant increase of irregular migration, in particular, labour migration, is defined as one of the most significant trends in world migration flows. According to the Organization for Economic Cooperation and Development, in 2017 258 million people were forced to leave the countries where they were born and lived, and more than 5 million of them received a permanent residence in the EU countries. On results of the year 2017, the total number of migrants from the countries of the Middle East and North America was 1.413 million people in Germany per 1 thousand of the permanent population, in France – 0.402 million, in Italy – 0.355 million, in Sweden – 0.328 million, in Latvia – 0.234 million [1]. The number of migrants arriving from Central America (Mexico, Guatemala, Honduras, El Salvador) in the US and Canada for the period 2017–2018 increased almost 5 times [2]. A number of negative effects of increased labour flows (increased population pressure on workers in the domestic market, reduced efficiency and productivity, increased pressure on social infrastructure, the lack of opportunity for reinvestment of earned money into the economy of a region/country of entry, etc.) led to an immediate reaction of the recipient countries in the form of widespread public protests, which the press dubbed "suicidal hospitality" [3].

3 Results and discussion

In Ukraine, for instance, as in most post-Soviet countries, statistical information on labour migration processes is provided by specialists from the Ministry of Internal Affairs, the State Committee on Nationalities and Religions, the State Border Service, the State Migration Service, the Department of Labour Statistics, the State Employment Centre of the Ministry of Labour and Social Affairs, the Ministry of Foreign Affairs, the Ministry of Education and Science, etc. Procedures for collecting data on labour is regulated by internal orders and directives of these agencies. Despite the recommendations of the UN on the need to create departments in certain ministries responsible for collecting such statistical information, in Ukraine none of the departments, with the exception of the State Statistics Committee, has such units.

State statistical agencies carry out the current registration of migration, using information on registration (in the past – residence registration/deletion) of citizens by processing statistical records of the arrival/departure address lists filled in at the passport office. The following documents for introducing registration act as the legislative framework: The Law "The International Labour Migration" dated November 5, 2015 [6], The Presidential Decree "On Implementation of Civil Registration as an Integrating System of Population Registration" [7], The Resolution of the Cabinet of Ministers "On approval of the Interim Statute for the Registration of Individuals at their Place of Residence" dated January 16, 2003 [8] and the Law "On Freedom of Movement and Free Choice of Place of Residence" of January 9, 2004 [9]. The main difference of the current accounting system is its constancy, which ensures the continuity of monitoring of the existing changes in labour migration processes. The unified methodology and broad regional coverage of data collection provides an opportunity to make inter-regional comparisons and to obtain fairly complete, objective information within the country. Recently, some significant changes have occurred in the current migration registration system related to the cancellation of residence permit and the introduction of registration, as well as the introduction of a new primary document for migration registration (lists for statistical data on arrival/departure) and a new data processing program in 1995. Such innovations, according to statistics, provide an opportunity to improve the accuracy and detail of information on the movements of labour.

The main source of data on the flow of international migrant workers is the "1-IM" statistical record form "Report on the number of citizens who are temporarily employed abroad", which was introduced in accordance with the order of the Ministry of Statistics (now the State Statistics Committee) dated May 30, 1996. Commercial offices, agencies and other organizations engaged in employment in other countries provide information on labour migrants who used their services during the year.

This source of official statistics covers only a few specific, in comparison to the overall level of the labour migration cohorts, participants who were employed abroad using the services of official intermediaries. Therefore it cannot serve as the main base for analyzing labour relocations, but is only an additional source of information [10].

Another important source of data on external and internal labour migration is the statistical reporting form of rural settlements "1-village". This form is not a part of the current population statistics, it is developed every five years and is filled for each rural population centre of Ukraine. The main information that can be obtained from this source is the number of villagers who are employed outside of it (in cities and urban-type settlements of the same region, outside the region or abroad).

The population census is the largest event of statistical population registration. As the named method of registration of migrations has little credibility, the requirements for the development of a population census program have been significantly increased, in particular, to include questions that should ensure the collection of statistics on labour migration. The main advantage of this source of information is that information is collected nationwide. It is also of great significance that the regular frequency of censuses usually takes place once every ten years. However, some authors note that such a periodicity of censuses makes it impossible to investigate the evolution of labour migration flows [11], others point to the inability of censuses to reflect rapid changes in labour migration [12]. In addition, the questions asked during the census in different countries differ significantly, making it difficult to estimate labour migration. It should be noted that in fact external labour migration excludes an individual from the census, therefore, information about the relocation is obtained according to their family members. In addition, censuses cannot provide complete objective information about the motives, circumstances, and consequences of labour migration, since they are conducted on a standardized questionnaire.

Population registers are considered the most reliable systems for collecting demographic information (including migration information). They are a database that is constantly changing and being updated thanks to current records of births, deaths, marriages/divorces, as well as changes in place of residence. Population registers provide information on each resettlement in a country for a specific period of time. In addition, this source of information provides the ability to obtain information about temporary migrations. Such data is not flawed, but more reliable than the data obtained from other sources. In some countries, for example in the Netherlands, the work of registers is organized so competently that the need for censuses is no longer relevant [13]. However, the registers have a number of drawbacks, namely, they can contain detailed information about migrants, but no information about the motivation of labour movement.

In the statistics of the countries of the post-Soviet space today there are no population registers, but there is an active discussion regarding their implementation. Creating such a source of information is facing a number of challenges. On the one hand, the legislative base of states does not contain documents that would oblige the population to provide information to the registers and to regulate an exact type of information, nor does there exist standards for using such information and guarantees of confidentiality. Besides legal, there are also material obstacles related to the need to acquire and maintain modern high-tech equipment, software, reliable communication systems, etc.

Speaking of border statistics, we note that it keeps records of border crossing facts, but not the number of migrants, including labour migrants. It is necessary to use the data obtained from this source with specified reservations, especially when it comes to determining the purpose of the trip, since it is noted depending on the type of visa received or according to what a migrant said. As a matter of fact, it is clear that such information is not always complete and objective.

Sample surveys that have a more flexible data collection tool can supplement the information on the number of migrant workers provided by various kinds of state institutions, organizations and agencies. All conducted sample surveys can roughly be divided into two types: specialized, dedicated to a deep analysis of labour migration itself, and general surveys consisting of various thematic clusters of issues, which may include a set of issues related to migration, including labour migration.

The development of sampling methods for the study of labour migration in a number of developed countries was largely due to the absence of an institution for civil registration at their place of permanent residence. A striking example is the experience of statistical registration of labour migrants in the USA and the UK. An alternative method is using the Central Population Register (for example, in Norway, Austria, Belgium, etc.), in which, as a rule, data on foreigners who are present on the territory of the state for a certain period of time, are recorded in addition to data on residents of a country [14]. It should be emphasized that sample study is widely used by both donor countries and recipient countries. The example of the main forms of such observations include studies focused on labour force – LFS (Labour Force Survey) (EU countries, Philippines, Canada, etc.), passenger traffic – IPS (International Passenger Survey) (United Kingdom, Mexico, etc.), population of the country (including demographic) – CPS (Current Population Survey) (USA, Mexico, etc.), households – IHS (Integrated Household Survey) (Bulgaria, United Kingdom), vocational training and qualification of workers – FQP (The Formation Qualification Professionnelle Survey) (France, Mexico, etc.), income and expenditure of families (household budgets) – FIES (Family Income and Expenditure s Survey) (Philippines, Poland, etc.), living standards – LSMS (Living Standards Measurement Study) (Tajikistan, Azerbaijan, etc.), as well as longitudinal surveys – LSI (Longitudinal Survey of Immigrants) (Canada, UK) [15].

First of all, we are interested in the experience of host countries that use sample surveys to statistically estimate the number of foreign citizens in their territory, in particular the UK and the USA. The tools of such surveys often contain questions about the interaction of the respondent with private employment agencies, since their

studying is important in identifying foreign workers employment mechanisms. Often they include blocks focused on commuting (Travel to work) and educational-related (Foreign Qualifications) migration [16]. In the UK, the National Statistical Office conducts a sample survey of international passenger traffic (IPS) at air- and seaports, at the border points of the English Channel Eurotunnel [15].

The vast experience of using selective research for collecting data on migrant workers has been gained in the USA. The reason for the wide application of this type of research is the absence of a residence registration. An alternative are special administrative sources of data on migration flows, which are targeted used only for international migration registration. Among the measured social indicators, those are of particular interest, which are related to the study of the mechanism of employment, and also aimed at identifying second-generation migrants through questions about the place of birth of parents [13].

No less interesting is the experience of researchers with respect to estimating the number of labour migrants in France, where, since 1950, labour force LFS surveys have been conducted (Labour Force Survey). This kind of research allows you to collect a database on the integration of migrants, both the first and next generations [14]. In Germany they conduct studies similar to LFS, which allows us to estimate the size and composition of both internal and external labour migrants. In Canada, a longitudinal study of labour force LSIC (Longitudinal Survey of Immigrants to Canada) is conducted, the methodology of which differs from that adopted in the EU. Its main purpose is to obtain information on how well immigrants integrate into local society and what factors contribute to or hinder this [13]. Particular attention should be paid to experience in conducting labour force surveys in the Philippines, where the national statistical agency through a number of different surveys of households collects information about citizens migrating abroad [14].

The procedure of collecting statistical information by means of forms filled in at the border is very complicated and cumbersome due to the growth of international migration flows. Only in Bulgaria, following the example of Great Britain, there is a special selective survey conducted to study international migration on the basis of border crossing facts. Poland, which uses census forms for all people crossing the border, abandoned this method of measuring migrations same way as Italy and Portugal [17].

Trying to draw parallels between EU countries and post-Soviet states regarding the methodology of researching labour migration, S. Ryazantsev noted that full-scale studies of external labour migration are conducted in Russia, Belarus, Kazakhstan and Ukraine, less regularly and massively in Moldova, Tajikistan, Azerbaijan and Uzbekistan [13]. The obtained data are systematized and actively used by the International Statistical Committee of the CIS [18]. There are some nuances of conducting such kind of surveys in different countries. Thus, according to the methodology of household surveys in Armenia, the number of labour emigrants includes family members who went to work in another country and have been absent for more than three months, while in Kazakhstan this period is extended to six months, in Belarus, Russia and Ukraine – to one year. And in Kyrgyzstan and Moldova, labour emigrants are considered to be all members of households who have left for work abroad, regardless of the period of their absence. No less informative are thematic and modular surveys aimed at studying the characteristics of internal and external labour migration, opportunities and ways of using migrant labour, the impact of migration and remittances on household welfare/poverty, etc. [19].

Systematizing information on means and methods for quantifying labour-migration processes, we note that most countries estimate labour emigration on the basis of sample surveys, while administrative systems are used to measure labour immigration, which are related to issuing work permits. We have summarized the experience of different countries that actively accept labour migrants or have a high mobility of the local population. It shows that the methodology for conducting such selective research is almost the same, except for the time and frequency of the survey, as well as the volume and content of the questions. The main reason for this is the coordination of the organization and conduction of sample surveys of employment of the population, labour migration in particular, by the International Labour Organization, the International Organization for Migration at the UN, the Organization for Economic Cooperation and Development, etc. The last of them conducts the most extensive studies on migration in general, and labour migration in particular. The methodology of these studies is based on the fact that population of labour migrants staying in the country can be assessed by appealing to data on the number of foreigners with valid work permits [20]. However, for many migrants, the presence of such a permit is not a guarantee of employment, therefore, it is necessary to take into account data on the number of foreigners who work in the recipient region or country. Among the main indicators that digitalise labour migration trends are the following: the number and proportion of the population born by migrants; the proportion of foreigners in the total population of the country; the number of foreign workers, including seasonal (temporary); the number and proportion of the foreign population and the population born abroad in the labour force; statistics of the legalization of illegal migrants by their countries of origin [13].

The variety of definitions and approaches to recording labour migration leads to significant statistical discrepancies in the values of labour migrant flows. Consequently, work on the improvement of statistics should be carried out in close contact with the services and departments that are responsible for managing labour migration processes. In particular, the development of the methodology for registration of external labour migration was provided by the project “Labour Statistics Improving in the CIS Region”, which was implemented in 2014-2016 by Statistical Committee of the CIS countries in cooperation with the World Bank [19].

The question of internal labour migration remains open, which has not been studied properly for a long period of time. The situation has become particularly

difficult given the reduction in the working-age population and the need for a more complete use of labour reserves. That is why it is extremely important to study internal labour movements together with the international migration of labour. Partially, the problem of studying internal labour migration is being solved within the framework of selective research of the population on employment problems, as they provide an opportunity to establish interregional migration links, demographic characteristics of labour migrants, and describe the sectoral structure of the sphere of their labour use. The balance in the labour market can be assessed by operating with data on available vacancies in the regional labour market and the volume of foreigners attracting.

A. Vorobiev, A. Grebenyuk, A. Topilin, summarizing the experience of conducting sample surveys of labour migration, made a number of recommendations:

1. Identifying the circle of respondents:
- members of household entrepreneurs (legal entities or individuals) who use migrant workers as employees in their enterprises or organizations;
- the head or members of households who employ labour migrants in their households (housekeeping, care and upbringing of children, care for the sick, disabled, retired people, residential security, refurbishing housing estates, landscaping, etc.);
- members of households of migrant workers who temporarily live in the territory of the recipient country;
- the head or members of households that include international migrant workers;
- the head or members of households that include internal labour migrants;
- the head or members of households with labour-migration intentions [14].

In our opinion, the proposed list should be supplemented with such groups of respondents as: external/internal labour migrants; labour migrants with previous experience in labour relocation and who returned to their permanent place of residence in the region/donor country; employees of intermediary companies engaged in the employment of migrant workers abroad/within the country; household members in the regions/countries of arrival; experts on labour migration (leading experts of the Ministry of Economic Development and Trade, Ministry of Social Policy, National Bank of Ukraine, United Nations Development Program (UNDP), International Labour Organization (ILO), National Institute of Demography and Social Research, etc.); employers.

2. Determination of the main blocks of questions included in the research tool:
- information about respondents (gender, age, place of residence, citizenship, level of education, place of education, profession, knowledge of the language of the country of arrival, place of birth of parents);
- job characteristics (type of economic activity, qualification, position, duration of work, professional experience, form of recruitment and wage, the nature and complexity of the work performed);
- job search (channels of employment, intermediaries when there are, the duration of the job search or organization of their own business);
- remittances (methods of keeping in touch with family, remittance flow, transmission channels, frequency, currency);
- causes of labour migration;
- labour intentions (motivations of movement, preferences regarding future employment, intentions to enhance education, qualifications, career growth) [14].

We find it appropriate to supplement the above list of social indicators measuring the dynamics of labour migration in accordance with the proposed groups of respondents with such indicators as:
- obstacles to adaptation in the region/country of arrival;
- plans for returning to a permanent place of residence, awareness of the activities of organizations, companies or ministries that provide information or assistance (of any kind) to people who plan to find a new job in the region/country of recipient;
- assessment of the effectiveness of organizations, companies or ministries providing assistance to migrant workers;
- the frequency and reasons for contacting the above organizations;
- the activity of migration networks, the presence of a circle of acquaintances labour migrants, the nature of the relationship with them;
- labour migration management mechanisms, assessment of their effectiveness;
- legalization of employment of migrant workers;
- the effectiveness of migration policies at the level of the state, region, etc.

4 Conclusions

In national studies, economic and socio-demographic approaches to the study of labour migration of the population prevail. They are characterized by limitations regarding the possibility of conducting statistical observations. Therefore, the methodology, theory and instrumental possibilities of sociological science, which are of interdisciplinary nature, are relevant for a comprehensive study of labour migration. In contrast to economists and demographers who use aggregated indicators of national statistics, sociologists rely mainly on sample survey data. Sociological research methods, including household sampling surveys, are based on descriptive analysis. And sociological models of labour migrant behaviour are more flexible than mathematical ones, which are used by economists. Even in spite of the fact that it is sociological models that are most often subject to empirical verification, they are more effective. The use of sociology in the study of labour migration processes allows to take into account the impact on the individual's decision to move a whole complex of modern trends in the development of society and the economy: unemployment growth and the impossibility of a steady increase in employment; growing inequality between countries; increasing the role of intellectual capital; reduction of opportunities for creative realization; needs of recognition from the environment; loss of a sense of individuality and the usefulness of work in connection with total computerization, etc.

Combining economic, demographic and sociological approaches will significantly enrich and complement both the analysis of labour migration and the analysis of the situation on the labour market. It also provides an opportunity to consider its elements as the result of objective and subjective aspects of the work of individuals, their internal and external stimuli and motives. Using such a synthesis, it is possible to segment labour migration flows, which in the future will contribute to the development of more effective state programs for regulating the movement of labour, attracting certain categories of labour migrants, programs for their adaptation and vocational guidance.

Summing up, we note that solving the methodology problems for conducting specialized sample surveys at the state level will help clarify issues of fundamental importance for users of this kind of data. The leading users are institutional structures (legislative and executive bodies) that are responsible for developing and implementing state migration policy. In order to expand the range of statistical information on labour migration, it is necessary to develop existing methods and forms of statistical observation. In addition, it's appropriate to supplement their organization with new means, drawing upon the leading experience of foreign countries in the study of this kind of problems. It is desirable to study labour migration as a whole as well as conduct deep, full-scale studies of its individual forms, in particular internal periodic circular migration, especially in the satellite regions of large cities, regional and industrial centres. Information on circular migration is necessary for the assessment and organization of transport flows, the effectiveness of the social sphere. The source of information on the integration of migrant workers, the effectiveness of the existing socio-cultural infrastructure and educational system, the satisfaction of career opportunities can be specialized surveys of their professional training and qualifications.

Thus, improving the range of means for obtaining data about labour migration, including population censuses, citizen registers, sample surveys of labour migrants themselves, their family members and others who are in one way or another involved in the movement of labour, is very important. In this way it is possible to obtain more complete, reliable information capable of filling in the gaps in the traditional types of statistical observation. First of all, by counting and expanding the list of social indicators that can be measured by sociological methods. That, in turn, will provide an opportunity to solve the issue of forecasting the dynamics of labour-migration processes and to optimize the social mechanisms of the state policy of regulating labour migration.

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Expert assessment systems to support decision-making for sustainable development of complex technological and socio-economic facilities

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Abstract. In this paper, we investigate problems of decision making in management systems for the sustainable development of complex technological and socio-economic facilities. We show both the limitations of traditional expert systems and decision support systems, and the necessity of using expert evaluation technologies to find possible development strategies. Based on that we substantiate the need of creating a new class of systems, i.e. Automated eXpert Assessment Systems, and propose their organizational structure and design principles. We substantiate the level of automation of the work performed during the examinations and describe the composition of models and computer programs we recommend for creating effective automated expert assessment systems and corresponding technology. In the paper, we give examples of using the proposed method for various areas of human activity, in the management of urban infrastructure and e-learning at the universities, and show the effectiveness of the developed approach.

1 Introduction

World leaders increasingly declare the need to protect the Earth from degradation by [1-5]:
• Rational use of natural resources,
• Introducing rational models of production and consumption,
• Taking urgent action due to climate change.

Indeed, recent years one may characterize by [6-12]:
• Increasing risks of technological disasters,
• Unemployment and social upheaval;
• Increased workload of people's activities at the cost of human errors;
• Food security threats.

Features of the modern stage of development of society such as [13-16]:
• Transition to a digital economy,
• Widespread use of e-government and e-society technologies,
• Introduction of complex hierarchical systems for managing enterprises, corporations, territories, technologies for ensuring the vital functions of regions, actualize the problem of finding quick optimal solutions for managing actions [1, 10, 12].

For such new complex organizational and technical systems that operate under high risks and uncertainty conditions, it becomes almost impossible to create a unified global mathematical model that is convenient for decision support.

In these conditions, it is increasingly necessary to use hybrid intelligence technologies and attract highly qualified specialists for expert assessment of possible scenarios for the sustainable development of production, society, region, state [1, 8, 17].

2 Problem analysis and research goals setting

Some simple choice problems one may reduce to mathematical models that allow finding the optimal solution for the problems. Unfortunately, the number of well-formalized problems is significantly inferior to the number of poorly formalized or non-formalized ones, for the solution of which the operation analysis methods are not suitable [8, 19]. The poor formalizability of many choice problems is associated with the presence of so-called uncertainty, which means that decision-making is influenced by factors that cannot be unambiguously defined and described for one reason or another [1, 18].

The nature and causes of the uncertainty can be very different, including [18, 20]:
• Incomplete or unclear information available,
• Stochastic nature of factors,
• Heterogeneity and subjectivity of the criteria for evaluating alternatives. Therefore, experts in the decision-making theory are constantly exploring and developing methods for describing and accounting for uncertainties of various kinds. For example, Lotfi Zadeh

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created the theory of fuzzy logic [21], which allows us to describe the ambiguity of statements. Currently, various logical-probabilistic and logical-linguistic models are widely used for modelling uncertainty [22].

Nevertheless, there are choice problems in which the uncertainty factor has not yet received a model that allows it to be adequately described and taken into account when searching for a solution.

In such cases, they speak of tasks of *unique choice*, i.e., arising for the first time in a sense [1, 23].

Often, when modelling complex hierarchical socio-economic systems, a task can contain several different types of uncertainty at once, which greatly complicates the search for a solution by formal methods focused on interacting with uncertainties of one particular type.

There is a specific area for such problems in decision theory – expert assessment methods, the cornerstone of which is the person himself with his subjective preferences as the primary source of the choice problem. The expert assessment methods are based on the assumption that it is possible to find, if not the optimal, then at least a good solution, analyzing the judgments and preferences of a person interested in choosing the best alternative.

In some cases, a subject in a situation of choice cannot independently sort his preferences, and then you need to help him in this. In other cases, the subject simply does not have the necessary level of knowledge, that is, cannot solve the task at all.

Then, just as when modelling a real object is replaced by its model, the original subject is replaced by an expert – specialist who has the necessary level of knowledge so that, based on the judgments and preferences analysis, the choice problem can be solved. As a rule, instead of one, a whole group of experts is involved in order to reduce the influence of the subjectivity factor and collect more information.

Unfortunately, it is believed that the presence of a large library of mathematical methods for expert assessment of alternatives, for example [22, 24-26], completely solves the problem of choice in managing complex objects.

In fact, the incorrect organization of expert assessment, especially in the tasks of planning the sustainable development of complex organizational, technical and social systems, can lead to incorrect guidelines and huge losses.

We set up an experiment in relation to:

• Planning socio-economic measures for the city development;

• Examination of educational electronic modules in the e-learning system;

• Selecting a vector for the development of an industrial enterprise (mechanical production).

The use of different expert groups and different methods for evaluating alternatives led to fundamentally different results.

In this regard, in this article we set the goal of determining design principles and system of measures that are necessary for automated expert assessment systems for decision-making to manage the sustainable development of complex technological and socio-economic facilities.

3 Results

3.1 Intelligent agent-manager for solving local problems of expert assessment

To solve local management problems, we propose using the idea of an intelligent agent-manager [27], which uses the most powerful intellectual resources (for today) – people. This agent, through interaction with millions of Internet users, provokes interest in specialists and seeks a problem to be solved, presenting the problem in a natural form (Fig. 1, Fig. 2).

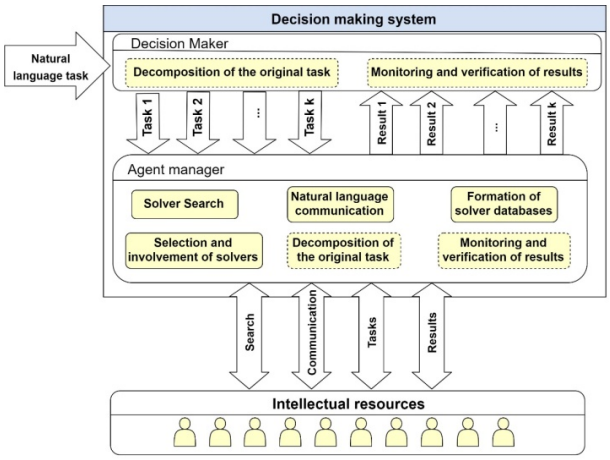

Fig. 1. Decision making system using agent-manager and intelligent solvers (idea taken from [27]).

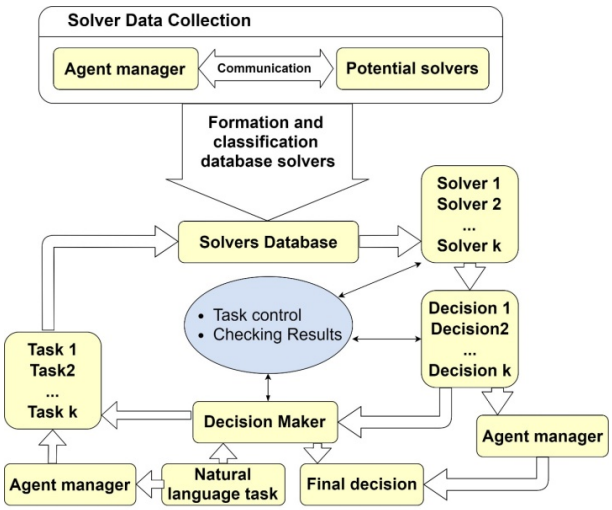

Fig. 2. Decision making principle (idea taken from [27]) using agent-manager technology (idea taken from [27]).

Agent-manager searches for users via the Internet and establishes communication with them. As a result of the agent's communication with users, a database is formed. Further, potential solvers, who fall into the database, participate in solving problems that the agent or decision maker (DM) offers them to solve for a financial compensation.

The problem description presented in natural language, as well as information about the material and time resources allocated for solving the problem, is fed to the system input. In some cases, before solving a problem, it can be convenient to decompose it. After the task is divided into *k* subtasks, the most suitable solvers are selected in the database of potential solvers. Selected solvers are given the subtasks, after which the agent-manager monitors the execution of work and after some time receives (ideally) *k* ready-made solutions. The *k* received decisions are analysed and, with the help of the agent or decision maker, are transformed into the final solution of the problem.

The advantage of the agent-manager technology is its promise.

The disadvantages of the agent-manager technology:
• The inability (at the present time) to solve complex tasks of a global level,
• The inability to attract outsiders to the solution of strategic tasks, security tasks, secret tasks,
• High risks associated with cybercrime.

3.2 The concept of an automated expert assessment system

For global complex tasks involving high risks and management costs, agent-manager technology cannot always be recommended for use. In this regard, we justify the need to create a fundamentally new class of systems – Automated eXpert Assessment Systems (AXAS).

Methods of expert assessment are not always directly aimed at solving the choice problem, and the purpose of the assessment can be associated with this task only indirectly.

The indirect goals of expert assessment may include:
• Assessment of the products quality and their compliance with certain standards and requirements,
• Forecast of the development dynamics and future state of the object of assessment,
• Development of a system of criteria and methods for object assessment.

In addition to the **expert group** acting as a collective decision-maker, the **working group** should play an active role in the assessment.

The **working group** is responsible for organizational aspects and the conduct of assessment, ensures the effective work of experts and the timely results presentation.

In accordance with the functions performed, one may distinguish the subgroups within the working group:
• managers – specialists who are directly responsible for organizing and conducting the assessment,
• cognitive scientists – specialists who are responsible for extracting expert information and communicating both the working group with experts and experts among themselves, if it is necessary to manage communication within the expert group,
• analysts – specialists who are responsible for the analysis and processing of information received from experts,
• technical staff responsible for supporting functions.

We can say that expert assessment methods are based on the principle: "*A bad plan is better than its complete absence, because even a bad plan makes it possible to meaningfully move towards a goal, controlling the process of achieving it*".

The process of achieving the assessment objective is divided into several successive (iteratively repeated) stages. Some of the stages can be completely formalized, and some of them cannot be formalized (at the current level of science).

Thus, assessment is a complex organizational and analytical activity, the implementation of which requires resources: specialists, premises, hardware and software, finance, and time.

The need for the effective use of all the resources leads to the formulation of the task of automating activities related to conducting expert assessment, i.e. the development and implementation of AXAS.

Non-specialists sometimes mistakenly believe that such systems have long been functioning. Unfortunately, most often they mean local (limited) automation. Indeed, various kinds of Expert Systems (ES) and Decision Support Systems (DSS) have been used for several decades. However, they have significantly limited capabilities.

ES are intended for mass use and enable specialists of insufficiently high qualification to use the experience and knowledge of highly qualified expert to solve the problems they face. ES can be used to perform diagnosis, training, interpretation, design, development of alternative solutions. The basis of any ES is knowledge about a specific subject area, which is structured, encoded in a certain way, accompanied by a set of inference rules and ready for use. Distinctive features of ES:
• The possibility of substantiating and explaining the obtained solution in a human-understandable manner,
• Focus on the application in a specific subject area for which it was specially developed.

DSS are computer systems which purpose is to support the activities of decision-makers managing decisions, in particular by providing a comprehensive and objective analysis of the problem being solved. This type of systems arose as a result of the merge of management information systems (IS) and database management systems.

The difference between DSS and ES is that the key role is played by the decision maker, who bears full responsibility for the decisions made and, therefore, needs complete control over the process of decision making and decision implementation.

Thus, neither ES nor DSS are an adequate answer to the issue of automating the assessment of decisions for sustainable development management of complex technological and socio-economic facilities.

The disadvantages of ES and DSS are that the both types of systems do not have the necessary properties of adaptability and universality, since they are initially oriented toward solving problems of a specific subject area. The specified properties should be possessed by a new generation system – AXAS.

AXAS should be much more than ES and DSS in terms of functionality, adaptability, coverage of the processes of assessment, intelligence.

AXAS main goal is to support all stages of the assessment, regardless of:

- Objectives,
- Assessment programs and techniques,
- Subject area,
- Selected assessment criteria and scales,
- Type of expert assessments and the method of obtaining evaluations.

The idea and organizational structure of AXAS are shown in Fig. 3.

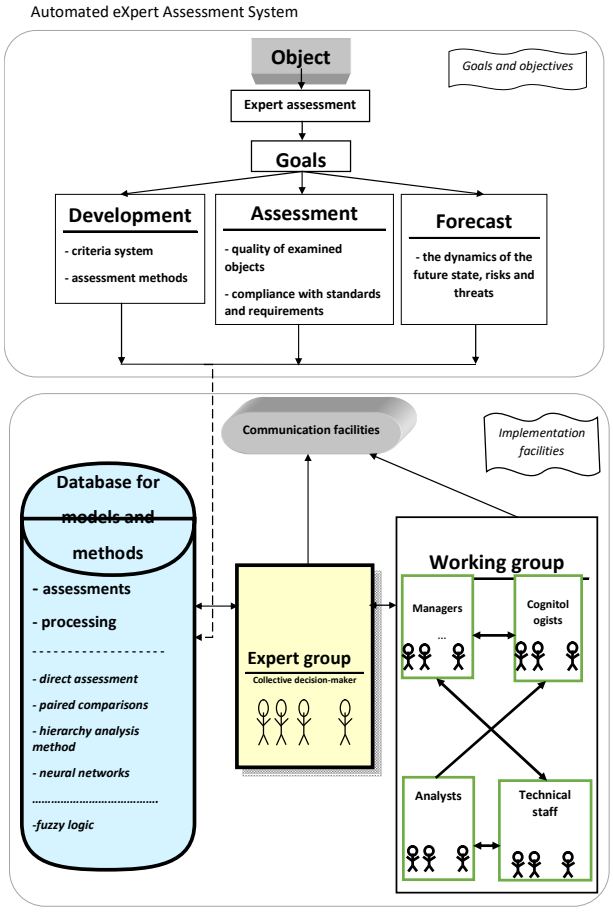

Fig. 3. Organizational structure of AXAS.

AXAS is a set of flexible customizable and arbitrarily connected software modules from which the system user will be able to assemble and configure a version of the system that fully meets the goals and objectives of a particular assessment.

The core of AXAS is an extensive set of models, methods and criteria used in data collection, analysis and processing for expert assessments (this is not just about an intelligent system, but about an ES development framework).

In addition to that, the practical feasibility of an AXAS design is largely determined by the degree of achievable formalization of the individual stages of the assessment, since it is hardly possible to automate what cannot be represented as a formalized model. Therefore, we further consider the main phases of assessment in regards with the possibility of their formalization and automation.

3.3 The phases of the assessment within an Automated eXpert Assessment System

Phase 1: Setting the goal of the assessment.

Participants and performers: assessment customer, working group (managers).

The phase is the foundation of the entire assessment and is carried out in the process of concluding a contract with the assessment customer – an individual or collective person asking for the help of third-party specialists.

The Customer and the assessment managers communicate, and administrative and financial issues are resolved.

Means (tasks) of automation (AXAS elements):

- Manager for searching experts,
- Communication facilities.

Phase 2: Software development and defining the assessment methods.

Participants and performers: working group, Customer (if needed).

This phase begins with the fact that the working group, including not only the managers, but also analysts and cognitive scientists, develops an assessment plan based on the purpose of the assessment, customer requirements, deadlines and available resources (financial, human, computational, etc.).

The working group determines: a list of intermediate tasks to complete (to achieve the global objective of the assessment), how the list items are interconnected, what resources are required, timelines, who is in charge for each task, etc. The assessment program should answer the following questions:

- What shall be done?
- When shall this be done?
- Who shall do this?

The determination of the assessment methods is carried out either in parallel with the assessment program development, or after the program has already been prepared.

For each intermediate task, working group selects an adequate tool from the extensive arsenal of expert assessment methods, taking into account resource limitations. The assessment methods describe how exactly each item of the assessment program shall be implemented.

As one can see, the phase of program development and determination of the assessment methods is a creative process and involves a large number of people.

It is unlikely to exclude human in the implementation of this phase (in the near future). Nevertheless, one may formalize the process of developing the program and determining the assessment methods, by presenting it in the form of constructing an assessment algorithm from a certain set of basic blocks that are adaptable to a specific set of requirements. What prevents the development of IS to support the work of the working group at this phase? Firstly, it is the scale of the work to be done by

the developers of such an IS: the range of methods and types of expert assessments is very wide and diverse, and creating a computer system reflecting this diversity requires considerable work. Secondly, the selected methods and algorithms of expert assessment have to be adapted to a specific task or subject area, and it is simply impossible to take into account all the nuances in advance.

Means (tasks) of automation (AXAS elements):

Visual editor allowing the working group to:

• Build and edit the assessment program in the form of a certain visual structure (using the project management methodology, including Gantt charts, etc.),

• Carry out meaningful filling of the program's blocks.

Phase 3: Expert group formation.

Participants and performers: working group, Customer (if needed).

The working group solves the tasks of examination aimed at the selection of experts. The selected experts will work to achieve the main goal of the assessment.

To accomplish the experts selection, at the previous phase should be defined:

• The structure of the expert group– homogeneous or heterogeneous, localized in time and space or not,

• The methods and the program of experts selection;

• The motivation of experts for the conscientious performance of their duties.

In a homogeneous expert group, all members have the same right to vote (number of votes). In heterogeneous group, experts differ from each other in the weight of their judgments, depending on their specialization, competence, objectivity, certain personal qualities, etc.

Sometimes, when conducting assessments, one may use the so-called expert assessments of the second kind are used: the judgment of each expert corresponds to a weight coefficient reflecting the degree of confidence in this judgment. Usually, they call such weighting factors "experts' competence coefficients", and their determination is an important task, since the quality of the examination results directly depends on the competence of experts.

The structure of the expert group also depends on the communication methods of the working group and the experts (first of all, the method of interviewing them), as well as among the experts. In some cases, it is necessary to bring all experts together to conduct a personal debate, in others, interaction with experts can be carried out remotely. Some types of interviews are based on individual work with each expert.

To determine the expert group composition, we propose the "snowball" method, when the core of the expert group is determined by the working group (for example, as a result of analysis of scientific publications of potential experts), and then each expert names specialists who, in his opinion, could be experts in this case. The new experts nomination is repeated until the expert group is fully formed.

Obviously, the choice of the structure of the expert group is ambiguous, depends on various factors, and therefore is hardly formalized.

On the other hand, the task of assessing the competence of experts and selecting candidates that meet the requirements is entirely conducted by the AXAS, but two conditions must be met for this:

• Firstly, such a system should contain models and methods for assessing various characteristics of experts: competence, objectivity, etc.,

• Secondly, there should be a database containing all the necessary information about experts, analyzing which, the system selects suitable candidates.

Means (tasks) of automation (AXAS elements):

Automatic multi-criteria selection of candidates meeting the specified quality criteria to form an expert group of a user-defined structure.

Phase 4: Retrieving expert information.

Participants and performers: cognitive scientists, working group.

The defining aspects of this phase are:

• The form of expert information presentation;

• The polling procedure.

The most convenient for formalization and processing are quantitative point estimates. Less convenient are interval estimates. This is due to the fact that the burden of formalizing the opinions rests with the experts themselves, albeit receiving assistance from information extraction specialists.

However, cognitologists together with analysts have to develop a system of criteria to be used by experts. This requires:

• Compile a complete (but not redundant) list of criteria,

• Determine the structure of relationships between the criteria,

• Assess the relative importance of the criteria (usually for this one needs to involve experts),

• Develop an adequate scale for each criterion and interpret its values.

The AXAS should support the development of a system of assessment criteria similar to that described at the phase of assessment program development (using the theory of project management methodology).

Various kinds of qualitative assessments (rankings, verbal estimates, logical judgments, etc.) are much more convenient and understandable for experts, however, formalizing them within the AXAS framework and processing accordingly is much more difficult.

The methods of interviewing experts range from extremely formal to completely free: from closed questionnaire methods to open debates between experts.

Therefore, human-machine methods and procedures for extracting expert knowledge, involving direct interaction between the expert and AXAS, cannot always be practically implemented, since this approach requires a high level of development and formalization of the survey procedure.

Means (tasks) of automation (AXAS elements):

• A visual editor that provides the working group with tools for developing and further modifying the system of assessment criteria;

• An interactive system that allows for an effective survey of experts;

• A database for storing expert information.

Phase 5: Analysis and processing of expert information.

Participants and performers: analysts and expert group.

Analysts analyse the information received from experts and process it in accordance with the methods, models and criteria provided by the assessment program and methods.

The degree of the tasks formalization at this phase primarily depends on the type or format in which the information received from experts. Analysis and processing of expert assessments is the most elaborated and convenient for automation, since most of the methods that comprise it are of a mathematical or statistical nature.

The complexity, as already noted in the consideration of the second phase, lies in the scale of the work associated with the implementation in AXAS of all possible methods and models used when working with different types of expert assessments.

Means (tasks) of automation (AXAS elements):

• A set of computer tools for the analysis and processing of expert assessments;

• A database storing the results of the examination.

Phase 6: Summarizing the results of the assessment.

Participants and performers: managers, analysts.

Based on the results of the previous phase, managers and analysts issue the necessary reports and transfer it to the Customer in the form initially established at the first phase.

In this case, the AXAS must generate flexible reports on the results of the assessment (using technologies such as OLAP).

Means (tasks) of automation (AXAS elements):

Digital reporting system with the possibility of flexible data visualization (such as OLAP).

3.4 Approbation

The experimental version of AXAS was fragmentarily used for:

• Development of urban infrastructure development strategies,

• Ergonomic assessment of complex systems including educational systems,

• A number of other complex objects.

The essence of determining priority areas for the sustainable development of the city is shown in Fig. 4.

Obviously, the budget allocation task is of interest to a huge number of participants in the budget process. The use of AXAS technology elements allowed for one of the regional centres of Ukraine to reduce social tension in both the city Council and the city as a whole, and to distribute budget money in rational way.

The idea of using AXAS for e-learning modules certification in a university educational environment[28-29] is shown in Fig. 5.

The use of AXAS technology made it possible, according to [30], to increase the design efficiency of the certified digital training materials database:

• In comparison to IS technology the efficiency raised 4.73 times,

• In comparison to non-automated technology – 17.5 times.

As a result, the quality of the educational process and the attractiveness of new forms of e-learning have significantly improved.

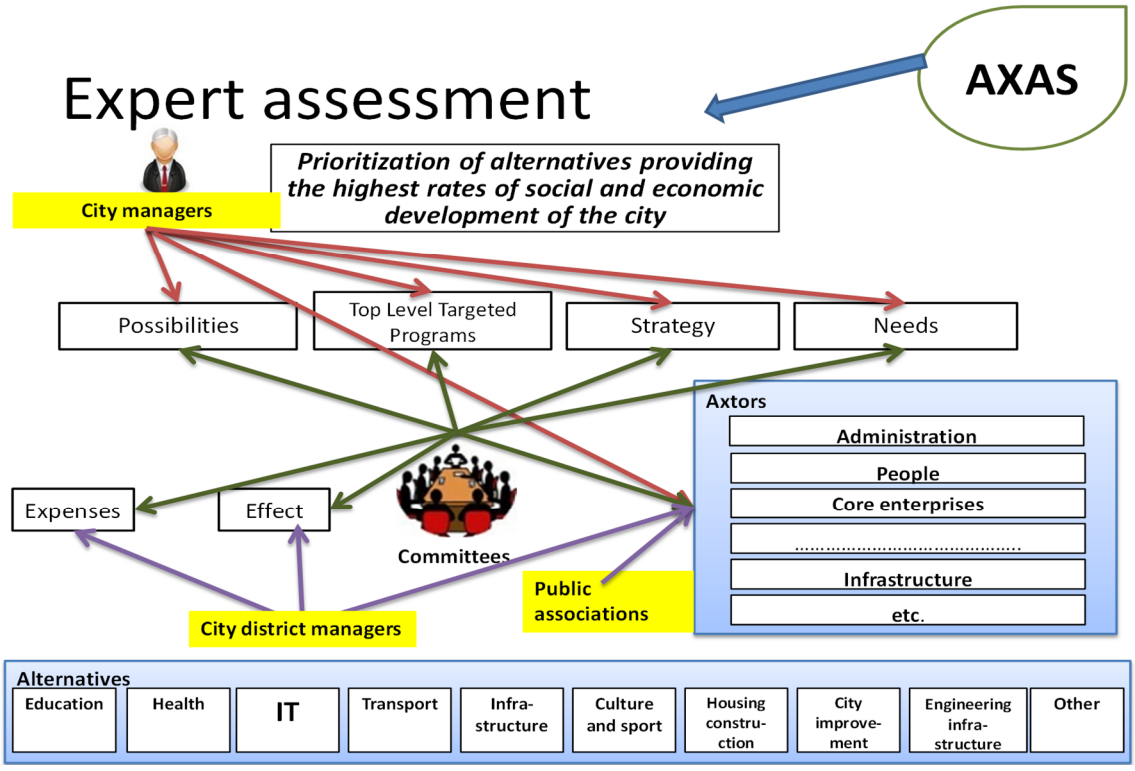

Fig. 4. An example of using AXAS to determine the priorities for the sustainable development of the city.

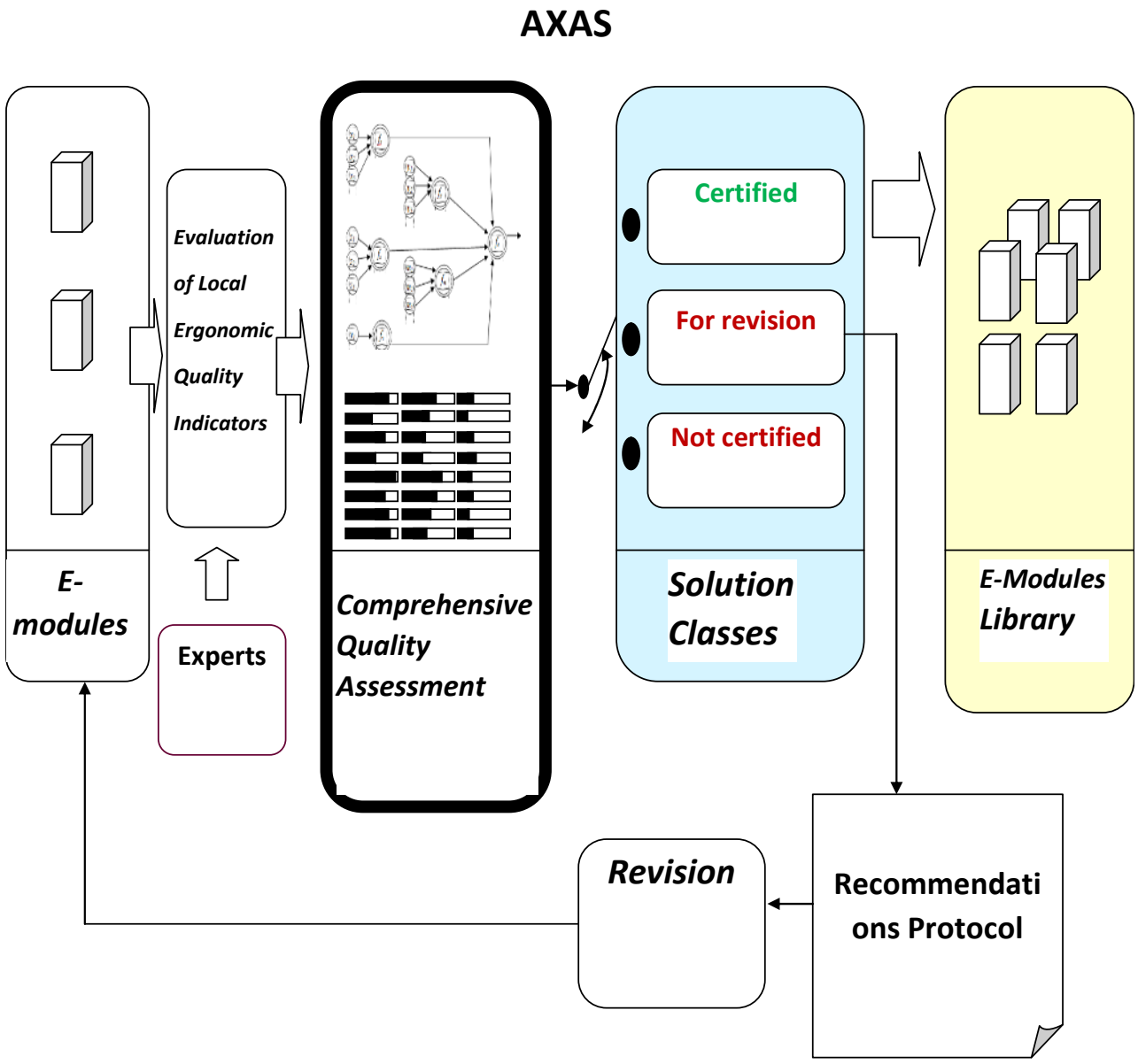

Fig. 5. An example of using AXAS for the ergonomic certification of electronic modules in the e-learning system.

4 Conclusions

Problems of sustainable management of complex socio-economic and technological systems require high-quality expert assessment of possible development scenarios.

There is an opinion that it is possible to automate the expert sphere of decision-making by replacing experts with databases of expert knowledge.

We showed that in many cases this is not entirely true, since many assessments are aimed at solving poorly studied or even unique problems, which only after they are studied and structured, can be solved by other more rigorous methods.

An effective solution to the issues of expert assessment is possible with the new class of systems proposed in this work – Automated eXpert Assessment Systems, which differ significantly from existing expert systems and decision support systems oriented to a narrow class of systems.

A justified degree of automation of expert assessment, as well as the set of methods and software tools can be recommended for designing effective automated systems for expert assessment.

The scientific novelty of the results lies in the fact that, in contrast to local models for obtaining and processing expert assessments focused on a usually narrow problem area, the developed technology allows to integrate existing methods and tools into one system. The system is flexibly configured for a specific problem situation and takes into account the capabilities of both human and computer decision support systems.

This creates the prerequisites for creating a fundamentally new generation of expert assessment systems based on hybrid human-machine procedures for making collective decisions (hybrid intelligence systems).

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Structural redundancy as robustness assurance of complex geoengineering systems

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Abstract. The present paper provides that robustness is the facility of complex computer-aided geoengineering systems of keeping its feature invariable along the certain period of time. The detecting of indications which testify that system is not responding adequately to input disturbances may be realized by: comparing real data on assembly output with number of reference artefacts which correspond to specific states of disturbances; comparing real data on assembly output with a normal reaction to the actual set of input signals. To increase the resilience of monitoring data of geoengineering system the majority principle and the Byzantine agreement method are used.

1 Robustness problem

Robustness [1–3] characterizes the complex computer-aided geoengineering systems (CCAS) facility of keeping its feature invariable along the specified time. After this time such characteristics may gradually deteriorate but with a decrease in quality of operation within predefined limits (by reducing dynamic and static accuracy, increasing response time, increasing transient intervals, reducing possible additional functions, performance/cost metrics, etc.).

Robustness study helps to understand better the characteristics of the complex systems, geoengineering, energy efficiency and building energy sustainability in particular [2]. It's used when there is a need for a functional layer to provide built-in protection to ensure that it is robust with respect to requests that are issued at instances that are incompatible with its current state and could therefore cause catastrophic system failure [3].

There are the following ways of robustness assurance: structural redundancy; procedural redundancy; informational redundancy; combination of the all or some of above mentioned redundancies.

Structural redundancy presumes the duplicating structures utilization while each of them is capable to realize all the necessary procedures and control actions inherent to CCAS. There are the following ways of using duplicating structures:

- Simultaneous functioning of the two (or three and more) structures (dynamic or "hot" backup) with their activity results analysis and the structure of fault occurred deactivating if the specifics of wrong operation is detected;
- One of structures is operating when the other one is in standby reserve and shall be activated only after the failure of the currently operating structure is detected.

Every of mentioned ways of duplicating has intrinsic preferences and limitations.

Redundancy is considering as an additional type of structural performance indicator that is defined as a measure of warning available prior to system catastrophe [4]. The redundancy can be evaluated and its quantification can be formulated with the help of characteristics of the geoengineering systems functions. For optimization of their operation it's important to control the effects of maintenance on lifetime functions and redundancy [4].

The existence of redundancy assists in enhancing the safety and reliability of a system in its intact state; and mitigating the sensitivity or vulnerability of the structure to localised damage under an accidental situation. To assure such characteristics of the systems it's possible to take into account various stages where redundant structures are involved in and to develop essential means of designing for redundancy which can readily be integrated into safety decision-making [5]. Such approach should be considered in underground and on-ground construction, in mining and the extraction of minerals, in the assessment of subsidence and subsidence of soil bases etc. Generalizing the problem of structural redundancy, it should be emphasized that it implies the introduction into the system of additional equipment, structured in such way that even in case of failure of a certain part of the equipment, the system will continue to function successfully [6, 8, 11]. All these need the reliable control of information, which is impossible without system reliability engineering and its predicting with reliability monitoring scheme under changing environmental conditions [7, 9-11].

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2 Structural redundancy

The simplest example of structural redundancy is the hardware duplicating and use in standby reserve either in dynamic or "hot" backup. In the first variant the one hardware is operating but the second one is idle or on maintenance prevention. In the second variant the both hardware operate simultaneously and supplementary monitoring hardware analyzes the operation of both complexes and makes a decision about what complex generates the more reliable information [12]. Each mode has the positive and negative distinguishing features. For example, the duplicating structure with standby reserve is developed in such way that after predetermined time of operation t_{rsb} when the probability of trouble-free operation

$$R = e^{-\frac{t_{rsb}}{m}} \frac{1+t_{rsb}}{m}, \quad (1)$$

(where m – trouble-free life) exceeds a certain set threshold, it is realized the transition to operating reserve set and the operated hardware is put on prevention for a time t_{mp}, during which the troubleshooting operations are carry out. It is the essential fulfilment of the condition $t_{stb} > t_{mp}$ while the more $\Delta t = t_{stb} - t_{mp}$ then the system's fault-tolerance is better. If the operating complex fails the standby reserve complex should be activated (if the last one isn't on prevention). This duplication approach is easy-to-work and requires the minimum of redundant hardware. But in case of failure and the need to switch to a backup set it is a loss of time connected with procedures for switching units, which leads to loss share information. If the standby reserve complex is on maintenance prevention the information drop may even result in overall fault. Therefore in such a case when loss of information and temporary stoppage of CCAS functioning are intolerable the dynamic or "hot" backup is used. In this case probability of failure-free operation along the time t_{hb} is estimated as:

$$R = e^{-\frac{t_{hb}}{m}} \left(2e^{-\frac{t_{hb}}{m}}\right). \quad (2)$$

In the case of "hot" reservation the complementary hardware is demanded for state analysis of every complexes and decision making of which of the blocks provides more reliable information. This hardware should also be duplicated in order to ensure its trouble-free operation. Therefore this way of structure redundancy is characterized by surplus of the complementary hardware as compared with standby reserve. Fault tolerance property in this case is guaranteed along the shorter time interval that is $t_{hb} < t_{sbr}$. But along that interval no losses of information in its unexpected fault from operating hardware occurs.

The detecting of indications which testify that assembly (subsystem, geoengineering system) is not responding adequately to input signals or disturbances, i.e. that it is a some loss of stability, may be realized by:

- comparing real data on assembly output with number of reference artefacts which correspond to specific states of disturbances (for detecting the cause of stability loss);
- comparing real data on assembly output with a normal reaction to the actual set of input signals (to detect the fact of stability loss).

Incidentally the distribution of points of set $Y_i{}^f$, which characterizes the real output signal is compared with distribution of points of reference signal Y_i^e and the Euclidean metrics

$$D\left[Y_i^f, Y_j^e\right] = \sqrt{\sum_{i=1}^{N}\left(y_i^e - y_i^f\right)^2} \quad (3)$$

is estimated.

If $D[Y_i{}^f, Y_i^e] < |\delta|$, where δ – maximum acceptable deviation of the real pattern from reference, the assembly is considered as correct one or corresponding to certain reference artefact.

3 Procedure of imbalance identification in systems

The algorithm that implement the above operations is presented in Fig.1-*A* –Fig.1-*D* and the conceptual layout of subsystem for some devices mismatching detecting and adjusting their features – in Fig.2. The following abbreviation is used here: UID – unit for information distribution, which depending on identical duplicating units' y_1 and y_2 state and subsystem's mode of operation, feeds the information on both units' inputs (if the loss of stability is not detected), locks out the inputs of both units (if the loss of stability is detected and faulty unit is identified) or locks out input of faulty unit (while correction procedure of the wrong data has place); UAM – unit of alternative models of assembly for the events of routine situation (proper operation, distortions due to specific common causes); URS – unit (source) of reference signals for testing the nodes and performing procedures for correcting the characteristics of defective nodes; UIE – unit of information's evaluation (the fact of loss of stability detection, fault unit identification, the optimal model selection); MU – memory unit for intermediate results of evaluations and corrections saving; UFC – unit of feature correction which implements the correction calculations in nodal points and choice of interpolation polynomials for calculations correction in all the residuary points of unit features.

In addition besides of majorization for fault tolerance the Byzantine agreement approach is used, which differs in that degree of redundancy need not to be as uneven number.

4 Principles of the resilience increase

As mentioned above, the further development of the method of structural redundancy consists in the use of the majority principle, or the principle of voting, which requires the introduction of multiple redundancy of data processing facilities, where multiplicity is an odd number equal to "3" or higher than it. When using majorization, the probability of a system failure can be determined from the expression

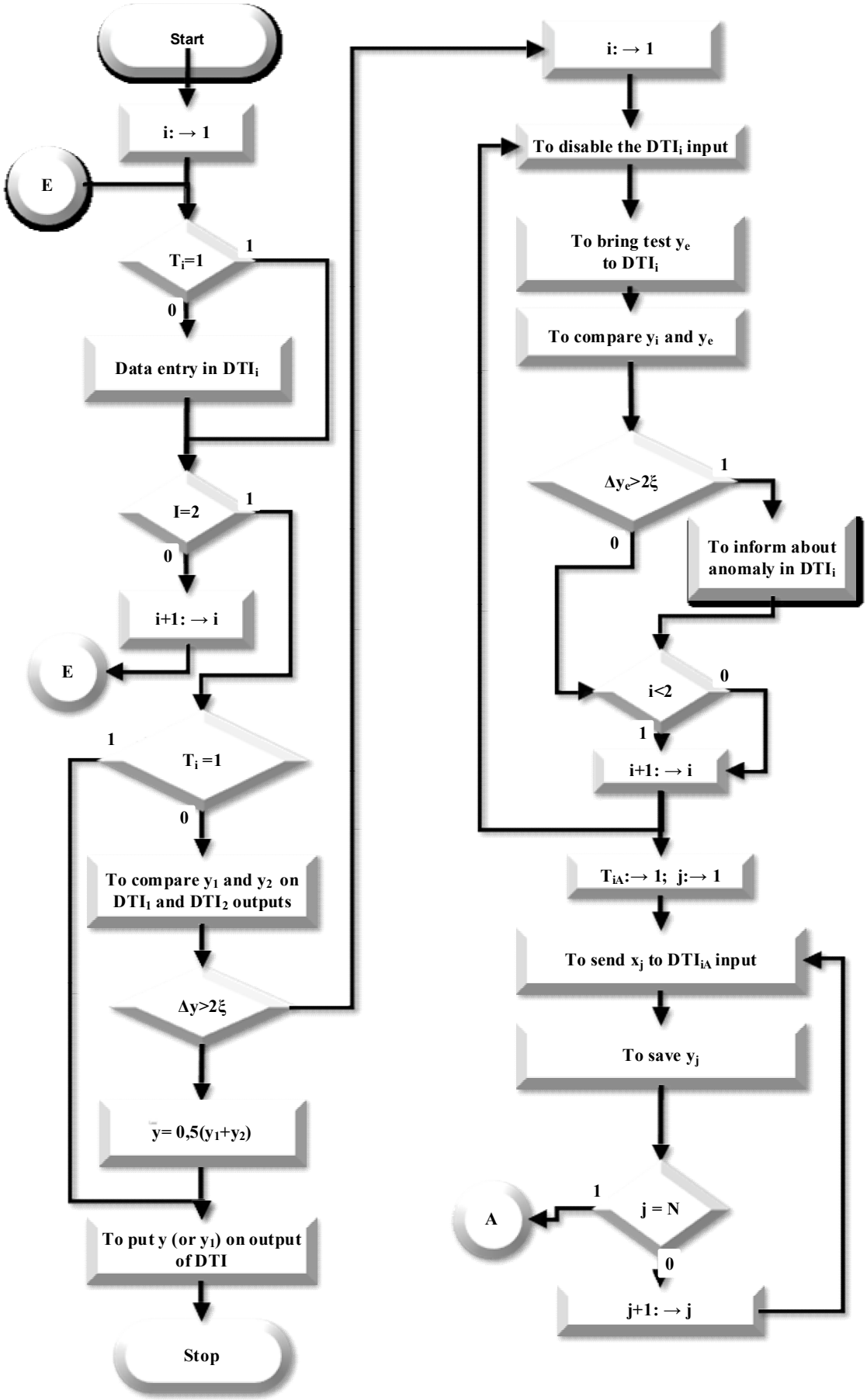

Fig. 1. The block-diagram of algorithm of imbalance identification in homogeneous subsystems which duplicates one another (*A*).

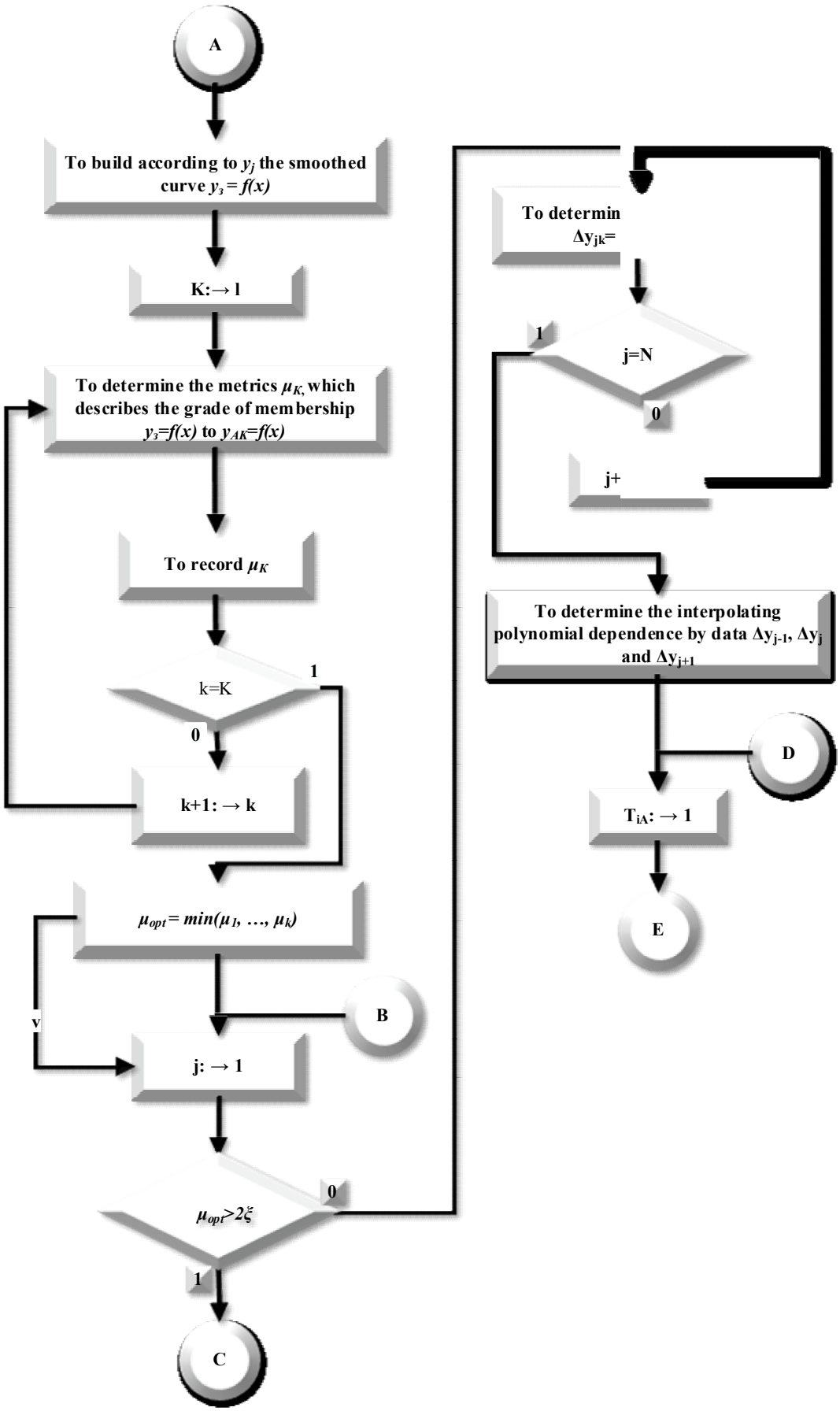

Fig. 1. The block-diagram of algorithm of imbalance identification in homogeneous subsystems which duplicates one another (*B*).

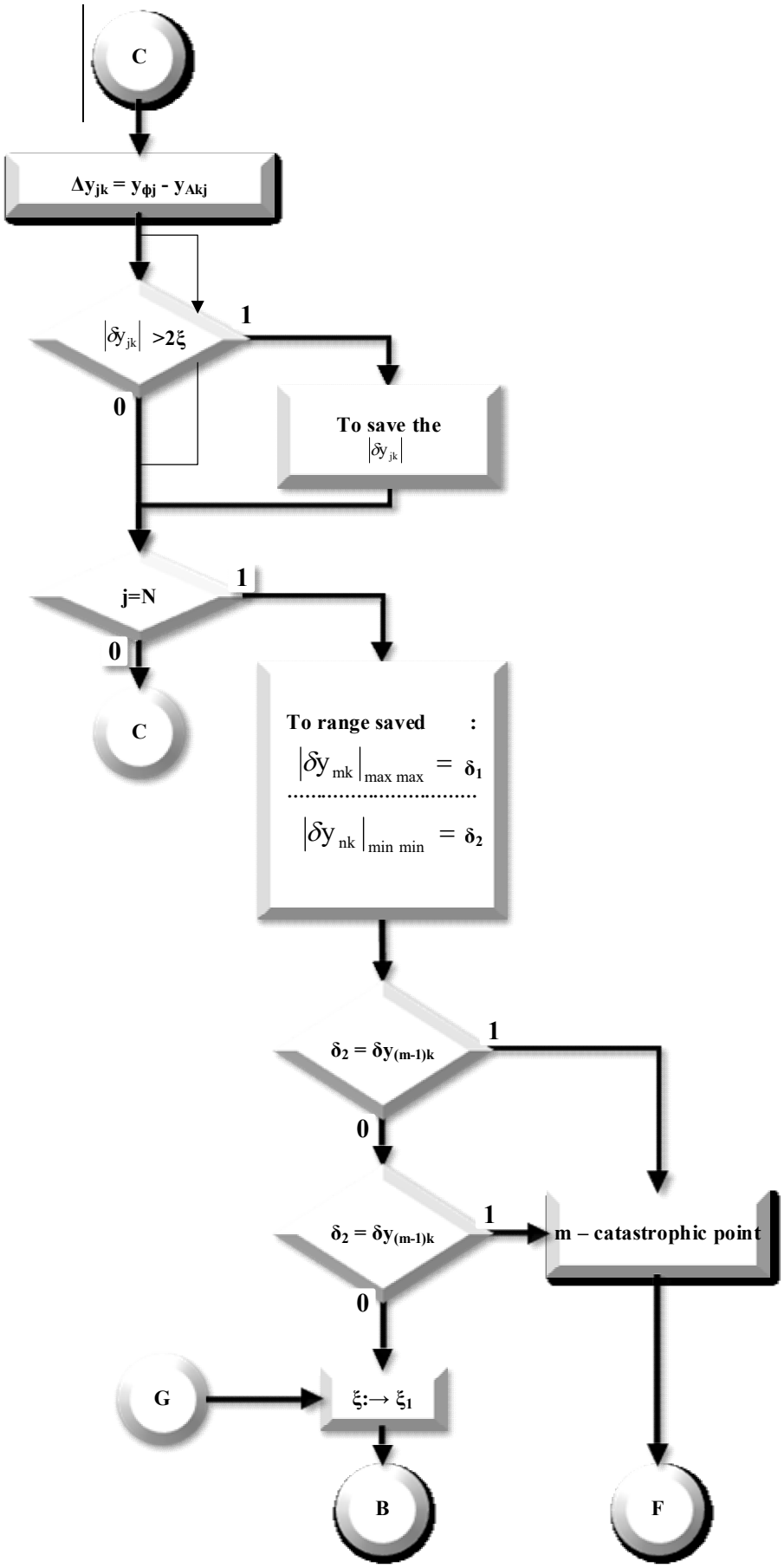

Fig. 1. The block-diagram of algorithm of imbalance identification in homogeneous subsystems which duplicates one another (*C*).

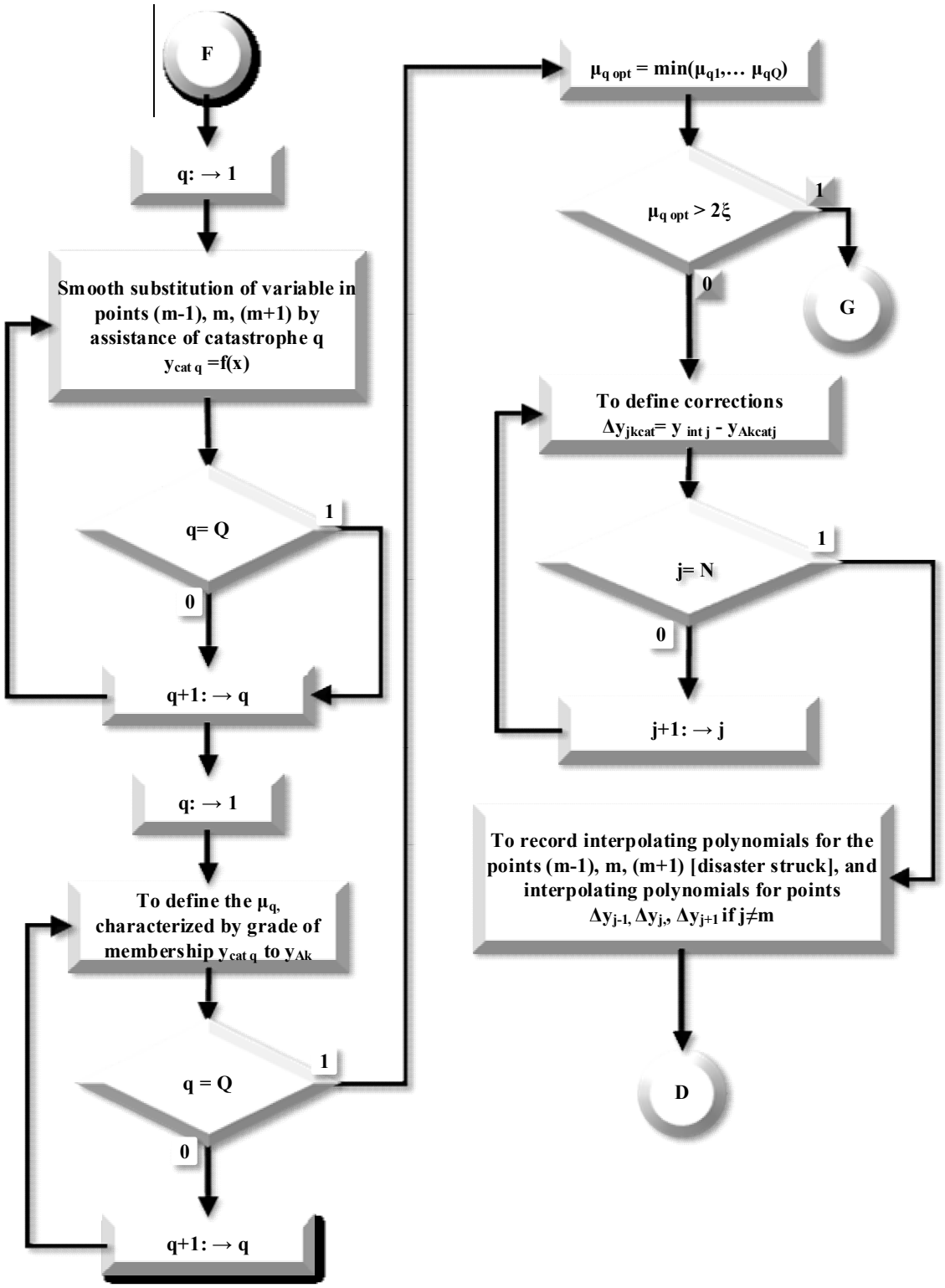

Fig. 1. The block-diagram of algorithm of imbalance identification in homogeneous subsystems which duplicates one another (*D*).

$$R_M = \left[\sum_{j=k}^{l} \binom{l}{j} R^l (1-R)^{l-j}\right]^n \qquad (4)$$

where n – number of sequentially connected blocks in the channel; l – number of channels, i.e. number of redundancies; j – number of properly operating channels ($j \geq k$, where $k = \{ l / 2 \}$ – the closest integer in excess of $l/2$; $R = e^{-t_{pM}/M}$ – probability of a single unit failing for time t_{pM} under failure conditions M.

Comparative characteristics of geoengineering systems using majorization principle with different redundancy values are given in Table 1.

In addition to the majority principle, the so-called "Byzantine agreement" is used to increase the resilience, characterized in that the multiplicity of redundancy is not necessarily characterized by an odd number. The formalism of the "Byzantine agreement" is effective when the total number of redundant (duplicate) blocks (duplication rate) is $n \geq 2k + m + 1$, where the blocks with failures are no more than k and m is the

number of blocks that did not fail.

When using Byzantine agreement the denied blocks may remain connected with the system in any way and continue to function. It is only necessary to add that in such systems the source of the initial data is assumed to be quite reliable.

In a simpler case, such an approach should be that the result of the re-decision is compared with the first decision and if they are the same, the decision is recognized as valid and the control procedure is completed.

If the answer is different, a third repetition is initiated and if its result is equal to one of the previously obtained during the previous two steps of the decision, the answer is recognized as valid and the procedure ends. If, however, the decision obtained in the third step does not coincide with any obtained in the previous steps, a steady rejection signal may be issued. Sometimes a steady rejection signal can be provided after most 4…256 series solutions differ from each other by a value exceeding a predetermined threshold or double standard deviation.

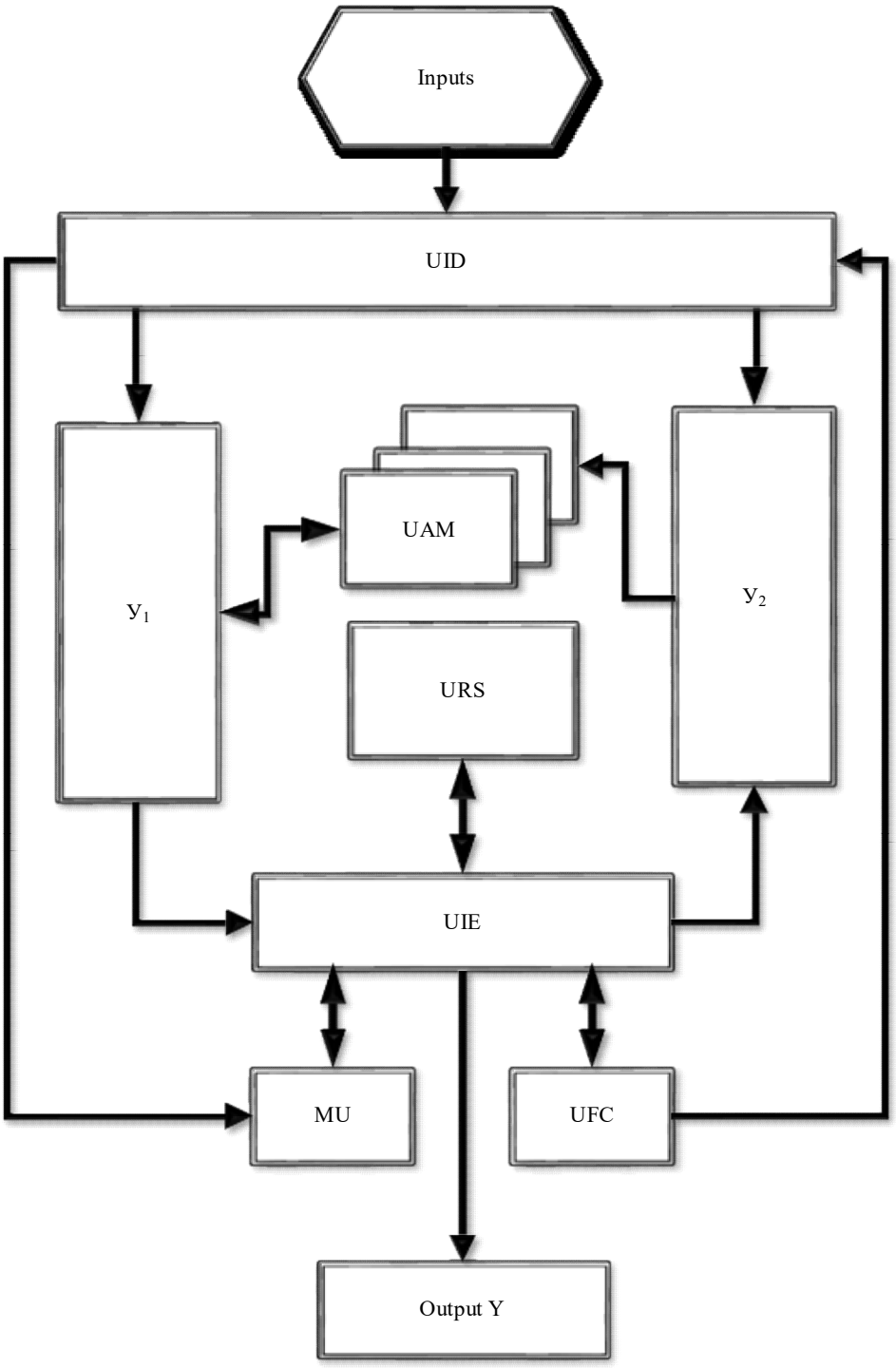

Fig. 2. Conceptual layout of subsystem for some devices mismatching detecting and adjusting their features

Table 1. Comparative characteristics of majorized systems with different meanings of redundancy rate.

Majorization	Probability of no-failure operation RM	Probability of system output emergency (1–*RM*)	
		R=0.9	R=0,99
2 from 3	$R_M = 3R^2 – 2R^3$	$2.8x10^{-2}$	$3x10^{-4}$
3 from 5	$R_M = 10R^3 - 15R^4 + 6R^5$	$8.56x10^{-3}$	$1x10^{-5}$
4 from 7	$R_M = 35R^4 – 84R^5 + 70R^6 – 20R^7$	$2.73x10^{-3}$	$3x10^{-7}$
5 from 9	$R_M=125R^5 - 420R^6+540R^7 - 315R^8+70R^9$	$8.91x10^{-4}$	$1.3x10^{-8}$
6 from 11	$R_M=462R^6 - 1980R^7+3465RR^8 - 3080R^9+1386R^{10} - 252R^{11}$	$2.96x10^{-4}$	$<10^{-9}$

5 Conclusions

Robustness can be ensured by procedural redundancy, which implies a multiple solution by the same problem using the same source data, with the conclusion, that the outcome of the decision is correct, is based on the evaluation of most of the same (or close) decisions.

In case of using the “hot” backup duplicating system which contains a module that provides a comparison of the results of the solution of each of the autonomously operating complexes, the same results obtained at the outputs of both identical complexes prove their authenticity. If these outputs differ one from another it may be realized recurrent solution with the same input data, and solution results are compared with the results derived by every subsystem on preceding step. The same result obtained twice by the same complex is considered valid. The decision regarding the second subsystem is made on the basis of comparison of the second of the obtained decisions with a reliable result. If they are identical, the failure is considered unstable and the complex remains operating within the geoengineering system.

Otherwise, it is excluded from the operating circuit of the system and switched to the steady-state source diagnosis mode. The above procedures can be performed either autonomously or as part of a triple redundancy system with a majority principle of assurance. In the latter case, they provide additional stability of the geoengineering system in case of failure of one of the blocks of the system.

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Modern processes of regional economic integration of Ukraine in the context of sustainable development

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Abstract. Ensuring economic sustainable development in difficult political and economic conditions is one of the priority tasks for Ukraine. It is forced to reorient the vector of foreign economic cooperation, in particular, the integration formations of the European Union. The aim of the article is to study the development of the processes of regional integration of Ukraine to ensure sustainable economic development, as well as determine the priority direction of its regional integration. The role of Ukraine in the processes of economic integration at the present stage of development is analyzed. Based on the analysis of the current state and development features of the EU and Ukraine, the prospects for the activation of its participation in integration processes, namely entry into the EU, are substantiated. By analysis, the domestic market of Ukraine, the general state of development and its place in the world market are investigated. As a result, the features and barriers of Ukraine's European integration and ways to address them were identified, as well as an attempt was made to identify the main areas of cooperation and ways to improve economic relations between Ukraine and the EU.

1 Introduction

"Ensuring the sustainable development of mankind is the most significant problem facing the world community". Such a statement was made in 1987 by the UN General Assembly [1]. And today, such a statement has not lost its relevance - the concept of sustainable development is constantly actively discussed by world leaders. The Sustainable Development Goals is a kind of call to action emanating from all countries - poor, rich and moderately developed. States recognize that poverty eradication measures must be taken by integration efforts to boost economic growth and address a range of issues in the fields of education, health, social protection and employment, as well as combating climate change and environmental protection, in particular economic stability.

According to the UN Development Program [2], in the context of economic sustainable development of the countries of the world, the following strategic objectives are set:

- To achieve increased effective international cooperation, including by paying special attention to the processes of regional integration.
- Support the economic growth of countries, including and on the basis of trade and economic ties between integration associations (in particular, the growth of gross domestic product at a level of at least 7 percent per year in the least developed countries).
- Increase the assistance provided by the Aid for Trade initiative to developing countries, especially the least developed countries, including through the Expanded Integrated Framework for the provision of technical assistance in trade to the least developed countries.

Having found itself in difficult political and economic conditions, Ukraine is forced to reorient the vector of foreign economic cooperation. In this regard, she is trying to strengthen ties, in particular, the integration formations of the European Union and intends to become a member.

Thus, for sustainable economic development, peaceful coexistence and effective international cooperation of Ukraine it requires determining the priority direction of integration, in particular, the main direction of Ukraine's foreign policy is Euro-integration.

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2 Literature review

Over the past half century, the concept of "integration" has become an important economic category in world politics and international relations. The focus was on such important problems of our time as ensuring conflict-free coexistence of states and developing effective cooperation, the functions and fate of a modern state, and the interaction of politics and economy. One of the consequences of globalization is the spread of regionalism, which should be considered not only as a tool to increase the intensity and efficiency of economic ties between neighboring countries, but also as a mechanism for collective protection of the interests of the countries of the region in the face of increased competition and instability in the world. The issues of optimizing the processes of founding and functioning of integration entities and the possibility of participating countries getting the maximum results from the association are constantly in the field of vision of scientists and politicians.

The consequence of globalization and integration processes was the creation and functioning of such entities as the EU, ASEAN, MERCOSUR, NAFTA, the CIS and others. A lot of research has been devoted to the concept of regional integration, in particular, [3-7]. Scientists not only explored the issue of regional integration processes, but also formulated the concept and identified the stages and forms of development of this process on a global scale.

Among foreign scholars, one can recall the work of Almira Enders, Zeno Enders, Mathias Hoffmann [8] some others who study regional integration processes in the current development of the geopolitical situation and its transformation [9]. Scientists study in detail both the existing regional integration and the new ones that arise under the influence of new factors and have new conditions and development goals, as, for example, Abdullah R. Alotaibi, Anil V. Mishra [10] study the associations of Brazil, Russia, India, China, South Africa (BRICS).

The issues of regional integration are especially relevant for Ukraine, since it seeks to integrate into the European economic and political community and paid a rather high price for this desire. The study used the research of domestic scientists: S. Didenko [11], O. S. Kvasha, A. V. Synyakova [12], S. V. Marynina [13], M. I. Nazarov [14], A. A. Ryeznikova [15], T. V. Shcherbyna [16].

The work [11] analyzes the functional structure of globalization as a driving force of world regional economic integration processes, indicating the prerequisites and results of the interaction of this sphere. The basic theories of regional integration are structured and modern regional associations of the world are classified using models of integration processes. A. S. Kvasha offers a scientific approach to determining the main parameters, areas of activity and principles of Ukraine's integration into the European economic, political and sociocultural space, forms the main basis for European integration processes in the economy regarding the economic part of the Association Agreement between Ukraine and the EU. In the work of S. V. Marinina, it was proved that regional integration processes have become the most influential factor in the development of world economic dynamics and an objective process of establishing sustainable economic ties and the division of labour of national economies, both close in terms of economic development and having significant differences in their development [13]. T. Shcherbina suggests looking at the processes of development of regional economic integration as a continuation and deepening of international cooperation within the framework of the concept of strategic partnership, in fact creates the ground for merging and interpenetration of economic systems, and is also able to explain the motives of international cooperation of countries [17].

However, this issue requires further consideration and study, since integration processes are constantly changing and developing.

3 Analysis of the development of regional integration processes in a globalized world

International economic relations have always had a great influence on the development of each country. Now all the countries of the world are somehow involved in the world economy. Therefore, the belonging of a country to one or a group of countries, an integration association, is of particular importance. Now in the era of changes in economic geography, namely: the transfer of priority from agriculture to industry and services, regional integration has the opportunity to strengthen the country's development in the system of international economic relations.

The development of integration processes in the modern system of international economic relations has become an objectively logical result of the growth in the movement of goods and factors of their production between different countries, which required the creation of more reliable supply chains between countries and the removal of numerous obstacles to international trade and the movement of factors of production. Interstate integration associations and multilateral political agreements have become a way to resolve many issues and solve international problems.

High rates of development of the global economy impose increased requirements on national farms, significant reserves of growth of which are laid in the sphere of integration.

According to A. Holikov's definition, the most important goal and result of regional integration is to increase the efficiency of using national potentials through mutually beneficial pooling of efforts and resources in solving problems of economic growth [7].

However, world experience shows that the advantages of regional integration in a certain way are manifested only if a comprehensive study of this process, strategy and tactics of its implementation. Otherwise, the positive effect of the transformation may be negligible.

Understanding regional integration as a manifestation of globalization gives reason to believe that the underlying driving force of such integration is the desire of participating countries to a higher level of development and to fall into a different level of international economic relations than the one to which they would objectively belong without such interaction. So in the current geopolitical situation, it is precisely regional integration associations that can cause global changes and stimulate development [6].

Researcher of integration processes Yakubovskiy believes that "the integrity created by regional integration is the integrity of a group of factors acting together in the process of globalization [3]. Therefore, this formulation is valid: regional integration is a model of conscious and active participation of a group of countries in the processes of ranking the world due to globalization, which confirms. As a result of trade relations, countries strive to increase efficiency and productivity, which is why the fact of unification into regional integrations is important for increasing rank in the system of international economic relations in the context of globalization changes" [4]. He created a scheme by which integration processes take place in the global world. First, there are prerequisites for the creation of integration processes, such as:

• similarity of levels of economic development of integrating countries;
• territorial proximity of states;
• common economic and other problems;
• demonstration effect;
• the domino effect (countries that are outside the bloc are developing worse, they are beginning to strive to join regional integration).

The main results of regional integration are:

- synchronization of the processes of economic and social development of countries;
- convergence of the importance of macroeconomic development indicators;
- deepening the interdependence of economies and the integration of countries;
- GDP growth and labour productivity;
- growth in production, cost reduction;
- formation of regional trade markets.

The concept of regional integration is formulated has a certain scientific novelty.

Firstly, a broader view is being made of the extremely dissimilar integration processes taking place in various regions of the world. Now all regional associations are preparing instruments of economic determinism, the main of which is the famous Bela Balashi scale of 1961. According to it, integration rises from the free trade zone to the customs union, further develops into a common market, and then turns into an economic and monetary union. From this point of view, the North American Free Trade Agreement (NAFTA) is still at the initial stage, and the Association of Southeast Asian Nations (ASEAN) is only approaching it. However, the Southern Common Market (MERCOSUR) is at the second stage, and the Economic Community of West African States (ECOWAS) is moving to the third. Therefore, according to this model there is no analysis of the goals of a country for cooperation [17].

Secondly, the new definition clarifies that integration is both a state and a process, provided that they are the current model. Political elites are not attracting their countries to integration associations in such a way as to intensify exchanges with their neighbors, as for a strategic perspective.

Thirdly, the proposed wording changes the concept of integration development indicators. Available methods for assessing the intensity of intra-regional exchanges, synchronizing fluctuations in macroeconomic indicators, disseminating supranational decision-making methods, and public support do not lose relevance, but turn into additional characteristics of integration.

According to T. Shcherbina, today modern international economic relations are characterized by rapid development of integration processes at the regional level, manifested in the creation of new groupings of countries and the expansion of existing ones. Since regional integration is most successfully and dynamically carried out by the efforts of the European Union (EU), the overwhelming majority of theories regarding the understanding of the features of these processes concern European integration [18].

The differences between the economies of a group of countries and the economies of an individual country are eliminated in the process of international economic integration and are characterized by the following:

- within one country, goods, services and labour move freely;
- goods, services, capital and labour that move from one region of a country to another remain within the framework of the system of laws of one country, including those that regulate economic relations;
- on the scale of a group of countries there are several currencies and central banks that regulate the circulation of money. In the regions of one country, one national currency is in circulation, which is regulated by the central bank;
- the international movement of goods, services and labour is the subject of special intergovernmental treaties and agreements, the provisions of which do not apply to economic relations operating within countries.

The reduction of these differences in their complete elimination is a process of international regional economic integration [19]. They can be eliminated only as a result of actions of countries or special international organizations. International economic integration can only be called an economic association, which is carried out by politically independent states and is voluntary.

Modern international economic integration is influenced by a number of factors of world development, among which the most significant are globalization and regionalization, which do not exclude but complement each other [20, 21]. Expanding, regional organizations are developing a mechanism of economic cooperation, which becomes the property of the world community at the global level [8].

4 Determining the priority of regional integration for Ukraine in the context of sustainable development

For Ukraine, there are only two possible options for global integration: European integration and regional integration. It is known that one of the leading and basic methods of self-determination of a country in modern times is participation in the integration process. However, Ukraine's integration policy has always been fuzzy and complex. This is due to the influence, on the one hand, of the European development model, and, on the other, of the non-European model of economic development. The non-European development model of Ukraine was membership in the EurAsEC, while the European one was in the EU.

As A. Reznikova notes, "an indisputable fact is that Ukraine belongs to European (Western) civilization. In addition, the priority of the European choice is due to the peculiarities of modern development, it is most evident among the EU countries, and is characterized by the deepening of globalization processes, the growing importance of the humanitarian sphere, high information technologies, post-industrial principles of social development, the increasing role of intellectual capital and management, social and humanitarian factors of economic progress, prioritization of the basic principles of sustainable development, which It is not only an economic upsurge, but also a fair distribution of its results, an increase in people's capabilities. Such approaches are fully consistent with the interests of Ukraine" [16].

The specifics of the formation of the geopolitical orientations of Ukrainian citizens is largely due to the fact that the country was at the epicentre of two integration waves – European and Eurasian, radically different in goals, conditions and nature. The inertia of the Soviet heritage, complex socio-political processes within the country, and powerful external influences were designated as citizens [23]. Under such conditions, the core of the supporters of the European integration course gradually formed and strengthened in Ukrainian society.

It is worth noting that since 2002 (the beginning of the sociological research of the Razumkov Center on this subject) the number of supporters of European integration constantly prevailed over its opponents. Russian aggression against Ukraine, which began in February 2014, radically influenced the picture of public sentiment.

Firstly, the attitude of Ukrainian citizens to the Russian Federation has fundamentally changed. In particular, the majority of respondents note the need to curtail or reduce contacts with Russia.

Secondly, the attitude of citizens of Ukraine to various integration vectors – European or Eurasian, was influenced by the Revolution of Dignity in December 2013 – January 2014, which defended and approved the European development course of Ukraine, as well as Russian aggression, which actually removed the Eurasian integration vector from the agenda for Ukraine. Eurasian integration is now associated by citizens, primarily with the aggressor country.

If during the pre-war years (2011-2013) the share of supporters of Eurasian integration was about a third of the respondents, then in subsequent years the proportion of supporters of the Eurasian Economic Union (the former Customs Union of the CIS countries) fell – in 2015 to 15.9%, and in 2017 it still fell to 7.8%. Accordingly, the share of supporters of the European integration path has grown [23].

Thirdly, since 2014, there has been a tendency towards an increase in European sympathies in society. In December 2017, almost 60% of Ukrainian citizens supported Ukraine's accession to the EU.

In addition, one of the directions of sustainable development for Ukraine is European integration, which means a way to modernize the economy and overcome technological backwardness. It is also a potential opportunity to receive foreign investments and the latest technologies, improve the competitive capabilities of domestic manufacturers, and access to world markets.
An important aspect of European integration is trade with EU countries. At the present stage, the EU remains the main trading partner of Ukraine (Table 1).

Table 1. The main trading partners in export of Ukraine in 2018 [24].

Countries	million dollars	% to 2017	% to common volume
Total, including:	47339.9	109.4	100.0
Belarus	1304.5	114.1	2.8
Egypt	1557.1	85.0	3.3
India	2175.9	98.7	4.6
Spain	1370.0	108.7	2.9
Italy	2628.8	106.5	5.6
China	2200.3	107.9	4.6
Republic Moldova	789.3	111.5	1.7
Netherlands	1603.5	95.7	3.4
Germany	2208.4	125.9	4.7
Poland	3257.6	119.6	6.9
Russian Federation	3654.1	92.8	7.7
Romania	932.7	110.8	2.0
Saudi Arabia	749.1	144.8	1.6
Slovakia	864.2	131.7	1.8
USA	1111.5	134.2	2.3
Turkey	2352.4	93.4	5.0
Hungary	1646.3	124.1	3.5
Czech	878.1	122.8	1.9
EU countries	20158.5	115.0	42.6

In 2018, Ukraine conducted foreign trade operations with partners from 221 countries of the world who acquired changes in the product and quantitative structure of foreign trade relations (Table 2). In 2018, the volume of Ukrainian exports to EU countries (28 countries) amounted to 23,032 mln doll. USA, which is 14.3% higher than the previous year. Imports from EU countries (28 countries) in 2018 amounted to 26,2851 mln doll. USA, which is 12.7% higher than in the corresponding period of the previous year.

In bilateral trade, a balance was maintained (Figure 1).

The found polynomial regression function (1) indicates a general negative trend between exports and imports for the EU countries.

The same trend persists for most of the studied EU countries (1).

$$y = 19{,}953x^2 - 370{,}23x + 607{,}77,\ R^2 = 0{,}55 \qquad (1)$$

Table 2. The main trading partners in import of Ukraine in 2018 [24].

Countries	million dollars	% to 2017	% to common volume
Total, including:	57141.0	115.2	100.0
Belarus	3787.0	118.1	6.6
Egypt	96.8	125.6	0.2
India	616.6	109.9	1.1
Spain	629.1	108.7	1.1
Italy	2031.1	125.0	3.6
China	7604.0	134.6	13.3
Republic Moldova	118.1	110.6	0.2
Netherlands	776.4	120.6	1.4
Germany	5983.2	109.9	10.5
Poland	3634.6	105.2	6.4
Russian Federation	8092.7	112.3	14.2
Romania	511.1	111.6	0.9
Saudi Arabia	186.8	102.1	0,3
Slovakia	525.7	103.3	0.9
USA	2962.3	117.3	5.2
Turkey	1714.2	135.8	3.0
Hungary	1267.8	110.0	2.2
Czech	1035.6	119.1	1.8
EU countries	23182.8	111.5	40.6

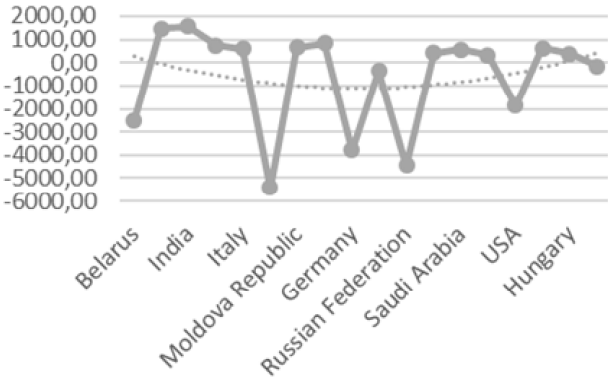

Fig. 1. Export-import balance of the main trading partners of Ukraine in 2018 (in mln doll. USA) [24].

According to statistic [24], the volume of trade between Ukraine and the countries of the EU increased by 55%. In 2018, the EU bought more Ukrainian goods than during all the time of bilateral cooperation. As for the Russian Federation, in comparison with the data of 2017, it is worth noting that the export of goods decreased by 7.7%, while imports fell by 14.2%. The export of Ukrainian products to the EU has reached record volumes in history and is growing rapidly, but the potential for economic integration is far from proper use. And then it is growing dynamically: over the eight months of 2018 it grew by 18.6%.

And its share in total Ukrainian exports is from 40% to 42.1%. In 12 out of 25 regions controlled by Ukraine, the share of exports to the EU ranges from 50% to 90%. Moreover, among them are not only traditionally Euro-oriented west, but also Donetsk and Lugansk regions, where the share of exports to the EU also reaches 50% of the total export and is higher than in some regions of Central Ukraine.

5 Conclusion

In order to ensure stable economic development of Ukraine, it should be noted that European integration is a strategic goal of the Ukrainian state, enshrined in law. The analysis of positive and negative consequences made it possible to assess Ukraine's potential with the potential use of the positive aspects of European integration and at the same time developing an action program for the painless integration of Ukraine, taking into account the existing threats and experience of countries that have recently become EU members.

At the moment, there are several arguments in favour of developing mutual cooperation between our country and the EU with a view to sustainable development and taking into account the characteristics of the Ukrainian economy:

1. The European Union is a large market, as well as a good market for importing products.
2. Trade with the EU is an important source of currency.
3. Production technology. Ukrainian enterprises lag behind their counterparts in advanced European countries, our country does not have the capital necessary to modernize existing and create new modern enterprises. Without modernization of production structures in Ukraine, it is unlikely that it can leave the path of sustainable economic development and overcome the growing lag behind economically developed countries. Access to the EU market, in turn, will open access to Ukraine to foreign investors and capital.
4. Access to the European market of Ukrainian enterprises is of great importance as a source of experience and practical skills in order to compete with manufacturers in other countries.
5. The development of cooperation with the EU will contribute to more efficient use of the potential of Ukraine as a transit state, which means an increase in revenues from the export of transport services and the development of related industries.

We can conclude that, given the influence of integration factors on the political, economic and social spheres of the state, Ukraine's entry into the European Union remains much more promising. Seeking stable development, positive changes are expected in the development of the Ukrainian economy, which will take place as a result of European integration. The cooperation of Ukraine with the EU will help bring closer social conditions of Ukraine with high European standards, increase living standards and well-being of the population. Membership in the EU guarantees the strengthening of national security of Ukraine and its protection from aggression and territorial claims.

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Company's strategic success as the basis of its potential sustainability

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Abstract. The study of corporate sustainability is becoming more relevant in the world economy, thus the connection between global economic processes and political, environmental and society problems was revealed by authors. Given research is devoted to the analysis of the processes of sustainability of Ukrainian and foreign companies. The results of studies of scientific works and interviews with different countries businessmen showed that the sustainable development of the same company should be considered in several directions, namely, in economic, social and environmental. Supporting new institutional concept research that focuses on the sector problems of company's stability, we have compared theories of corporate sustainability and corporate social responsibility and highlighted the economic dimension as a basis of company's sustainable development. As a result of our research in economic directions of corporate sustainability the *Methodology of evaluation of company's sustainability potential* was proposed. The suggested methodology can ensure corporate sustainability for the strategic period. Proposed in the paper methodology assesses the strategic potential of company's success, its competitive status and capacity potential, and transform capabilities into competitive advantages. The implementation of the *Methodology of evaluation of company's sustainability potential,* according to authors view point, can be proposed as the basis of strategic management in forecasting and planning processes in industrial companies.

1 Introduction

During the period of development of "economic states" that are characterized as transnational and multinational corporations, as well as international economic-political alliances and international alliance networks, it becomes evident that active consolidation of different countries economies creates the basis for effective international cooperation. In its turn, the potential basis of international corporate cooperation of each country is the process of structural and economic consolidation of business entities and the creation of corporate associations. Thus, within individual economies it can be formed either cores of future transnational and multinational corporate entities, or the structural units of existing companies of domestic and/or international corporate business. The expansion of the corporate sector in certain branches of economies of the developed countries gives them the growth of GDP and export sales, but countries with weaker economic development obtain only opportunities to attract investments into the economy. It should be noted that the processes of creating global corporate systems are a manifestation of the consolidation of economic, labor, energy and other resources at the level of international economic and political cooperation, and thus form the basis of the world system of specialization and cooperation.

It was revealed that the key to the company's effective development is its financial and economic stability in the market. Corporate sustainability is especially important in the international markets operating under conditions of high volatility and emergence of competitive environment. Contemporary competitive markets require companies that respond quickly and flexibly to the challenges of the environment, and thus have high sensitivity to the actions of competitors, which can be transformed into partners. From the authors' point of view, the corporate sustainability is directly related to the concept of successful activity potential.

Our authors' group interprets the company's "strategic potential of success" as a set of available resources, opportunities and strengths, which in favorable market conditions for the company can be transformed into competitive advantages, increasing profitability and cost-effectiveness. The authors' stress that it is precisely the high level of company's strategic potential of success is the basis of its sustainability. The global rankings of successful companies with constantly increasing revenues that ensure stability of their development and leading

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positions in the ratings confirm author's position on the problem.

Analyzed public information confirms that the sustainability of modern companies is one of the top topics at international economic summits. During the work of New York Sustainability Summit (July 16–17, 2019) the opportunities to achieve success in tangibly improving environmental, governance and social (EGS) conditions were discussed. This Sustainability Summit has provided a unique opportunity for sustainability practices for leading companies to get specified knowledge how to be the best in the business and be able to generate EGS impact [1]. The main objective of the 3rd Annual Strategic CSR & Sustainability Summit (July 4–5, 2019) in Mumbai was a decision making of creation an important tool for protecting and enhancing the goodwill, defending attacks and increasing competitiveness [2]. The participants of the 18th annual Responsible Business Summit Europe, London (June 10–12, 2019) discussed problems of such global pressures on business as climate changes, investors, new consumer reactions, innovations etc. The RBS-2019 "has ambitious plans for 2020 with 750+ of the world's leading CEOs, Heads of sustainability and investors convening in London 2020" [3].

2 Literature review

What is the concept of corporate sustainability? The views of companies and global organizations on this issue are somewhat different.

For the first time, the concept of sustainability was formulated by the Brundtland Commission in 1987, and later this term was used in the concept of sustainability at the 1992 UN Conference on the Environment in Rio de Janeiro [4]. The UN General Assembly defines the concept of corporate sustainability, the "global model of future civilization", as a development strategy that has emerged in response to the growing threat of an environmental crisis. This strategy combines three areas of company's activity: economic, social and environmental. Therefore, from the UN's point of view, the economic benefit of a company must take into account not only its profit but also the pressure on the environment [5]. In this situation, the global community perceives one of the main tasks of corporate business in reducing environmental risks by constructing or upgrading treatment plants, dramatically replacing the raw material base of production processes, and other technological changes that can protect the environment.

Company management perceives corporate stability as such, a source of profitability and efficiency, and thus considers the concept of "sustainability" in conjunction with "corporate social responsibility". Quite often, business representatives identify these definitions.

"In Unilever instead of social responsibility we prefer the term "corporate sustainability" as the strategy that underpins our business operations; … when Paul Polman presented the Plan of Sustainability and Quality of Life to the world in 2010, it (we mean our corporate strategy) was fully revealed" in the form of "reducing the environmental impact, improving sanitation, creating opportunities for women ..." [6].

Reviewed results of McKinsey Company's research on corporate goals, incentives and motivation for corporate sustainability have shown that among "reasons for pursuing sustainability, from reputation management to operational improvements and new growth opportunities, the overall high degree of integration seems to indicate that companies have become more businesslike about their sustainability agenda. Most companies, however, are still struggling to factor sustainability into the "hard" areas of their business, such as supply chain and the budget, so there is still a lot of potential to drive further integration and increased value creation" [7].

Representatives of Ukrainian corporate business treat sustainability not only from the point of view of economic benefits, but also consider its impact on the environment, economy and society. Such companies as Deloitte, Mriya Farming PLC, JSC "Ukrainian Railways", consider upholding the interests of workers, their proper decent conditions, job creation, and openness of their own corporate policies for both clients and investors as the basis of their own sustainable development [8].

Thorough analysis of the literature on the problems of sustainable corporate development conducted by foreign scientists indicates, in its turn, the existence of supporters of different view points on the concept of corporate sustainability (CS): "… some articles identify CS with corporate environmental issues. … some other studies used the term to refer to corporate social issues, which is, the social sustainability aspect of the firm. Finally, there are articles that take this approach and identify CSs with both social and environmental issues and how they relate to economic sustainability". [9]

Such authors as Montiel and Delgado-Ceballos conducted investigations on determining and evaluating the level of company's sustainable development on the basis of theories of stakeholder, institutional, resource-based, corporate sustainability and subsequently concluded that companies need non-financial reporting that allows the public to get acquainted with the company's activities and evaluate it from the point of view of efficiency for customers and society. Such openness, in their opinion, also increases the interest of investors to companies [10]. Hussain, Rigoni & Cavezzali investigated the relationship between sustainability performance (SP) and financial performance (FP) of company. As a result, a model of assessing the impact of sustainability performance (SP) on financial performance (FP) was proposed, such a model allows us to assess the financial value of the stability of a company's development [11]. Peculiarities of corporate reporting with the goal of creating a positive image of the company, the advantages of financial and non-financial reporting from the point of view of planning sales volumes are presented in the works of a group of Singaporean scientists [12].

Research in the field of investor attraction to the company, taking into consideration the stability of its development as a leading factor in investment attractiveness, is conducted by a group of scientists of Harvard Business School as Grewal, Serafeim and Yoon. "Managers may not act in the best interests of

shareholders but rather respond to engagement on immaterial proposals in order to satisfy the sponsoring shareholders and protect their reputations" [13]. In terms of analyzing the impact of social responsibility on the investment attractiveness of the company, Ioannou I and Serafeim offer a model of assessing the level of the company's attractiveness for investors [14]. In their further researches, Serafeim and co-author Hawn reveal the dual nature of Corporate Social Responsibility (CSR), which perceive a significant difference between the company's internal need to increase production and the external need to adhere to socially necessary standards of output with regard to corporate responsibility [15].

Continuing their research, representatives of the London Business School and Harvard Business School, such as Ioannou and Serafeim, studied the strategic nature of corporate stability and proved that stability is one of the leading aspects of the company's long-term strategy necessary for practical implementation in company's activities [16]. In their scientific studies, Adams and Larrinaga explored the process of increasing the interest of companies in different countries in analyzing the causes of sustainability and studying the results of sustainable business development. The results of their research in the period from 2007 to 2017 showed not only the expansion and improvement of the methodological base of accounting and analysis of corporate sustainability, but also confirmed the fact that the study of corporate sustainability is one of the main goals of company's corporate strategy [17].

Considering the above scientific positions, we note that corporate sustainability is directly connected with questions of environmental protection. Moreover, with an account of the revenues entering of corporate business, the public consciousness of management should take into consideration the necessity of allocation certain share of profit to reduce the environmental risks from corporate activities. However, our authors' group is leaning toward the thought of those scholars who separate the positions of economic and social views on the corporate sustainability. From our point of view, the sustainability of one and the same company should be considered in different directions, such as economic, social and environmental. "… that organizations that voluntarily integrate environmental and social policies in their business model represent a fundamentally distinct type of the modern corporation, characterized by a governance structure that in addition to financial performance, accounts for the environmental and social impact of the company, a long-term approach towards maximizing inter-temporal profits, an active stakeholder management process, and more developed measurement and reporting systems" [18]. It is the consideration of corporate sustainability in the economic direction that is suggested in our studies.

Generally speaking, the proposed research is now in the process of being tested and practical results are not yet confirmed. But our author group continues our research in the area of accumulating of company's potential success, increasing competitive status and ensuring corporate sustainability.

3 Methodology of researching

The authors of the report have appraised the *Methodology of evaluation of company's sustainability potential*, that allow them to assess the strategic potential of company's success, competitive status and ability potential for strategic development of the company. The *Methodology of evaluation of company's sustainability potential* can become the basis for strategic forecasting and planning in industrial companies.

Methodology of evaluation of company's sustainability potential includes the group of methods that can be consistently applied in industrial companies' strategy of sustainability:

1. Method of assessing the strategic potential of company's success.
2. Method of estimating the company's competitive status.

4 Results

4.1 Method of assessing the strategic potential of company's success

According to authors' point of view, the possibilities of using one's potential depend on the competencies and resources of the company. The complexity of the problem determines the necessity for a balanced distribution of tasks within the strategic management of potential of success. The essence of the matter is to identify market potential using strategic means of "early detection", which include methods for assessing company's resource potential. The first and the most important of the proposed methods is the Method of assessing the strategic potential of company's success.

Conducting research in corporate sustainability area we concluded that magnitude of the strategic potential of company's success is characterized by the level of strategic reserve, which is necessary for its successful sustainability. By "successful sustainability" we mean only the break-even activity but not profitable one, because in the Ukrainian economy the break-even tendency for the most companies can be described as a prospect of stability and success.

Method of assessing the strategic potential of company's success, which is based on determining *the ratio of potential capacity estimation (RPCE).* The *ratio of potential capacity estimation* is calculated by dividing the value of existing capacity potential (ECP) into the value of required (planned or necessary) capacity potential (RCP) in scoring system, and these values are estimated on a scale from 1 to 10. Consequently, the potential of success is determined by dividing the total ratio of potential capacity estimation (according to estimation parameters) by the sum of evaluation parameters.

In order to calculate the *strategic potential of company's success*, our author team proposed formula (1).

$$\mathrm{SPS}_{\mathrm{comp.}} = (RPCE \times (PCP + DSA + PLSBU))/100 \quad (1)$$

where *RPCE* – ratio of potential capacity estimation, *PCP* – prospective capacity potential, *DSA* – degree of strategic adaptation of company with the optimal strategy, *PLSBU* – perspective level of strategic business units.

Authors propose to take the optimal value of the strategic potential of company's success for 100%, as a priori under normal conditions the company has a 100% success rate of activity due to the existing corporate strategy. Therefore, in order to determine the magnitude of the strategic potential of company's success in the given conditions, it is necessary to compare this value with the optimal value, that is, to divide by 100%. Then the magnitude of the strategic potential of company's success can be characterized on the following scale:
- from 33.5% – low SPS,
- from 33.5% to 70% – average SPS,
- from 70% – high SPS.

The benchmark of the proposed method, *the ratio of potential capacity estimation (RPCE)* allows establishing proportional relationship between the value of the *existing capacity potential (ECP)* and the value of the *required capacity potential (RCP)* of the company to ensure its future sustainability. It should be noted that the above-mentioned *ratio of potential capacity estimation (RPCE)* actually makes it possible to determine the average value of company's capacity at a given time, taking into consideration its existing and required values. Thus, the *ratio of potential capacity estimation (RPCE)* is firstly calculated according to each internal factor of potential capacity of functional units of company with the subsequent determination of their sum, and then for the company as a whole.

In order to calculate the *ratio of potential capacity estimation* of the company by the factors of potential capacity it is necessary to carry out formula (2).

$$\mathrm{RPCE} = \frac{ECP_{iex.fact}}{RCP_{ireq.fact}} \qquad (2)$$

where $ECP_{iex.fact}$ – existing capacity potential of *i*-th factor, $RCP_{ireq.fact}$ – required capacity potential of *i*-th factor.

Such indicators as the level of the existing capacity potential of company and the level of the ratio of potential capacity estimation for each functional unit we determine according to scale of 1 to 10. We suggest ranking the levels obtained at low, average and high levels according to the proportional distribution of their importance within the above scale, the range of which covers 100% assessment the internal capacity potential (ICP) of company's functional units and of company as a whole.
- from 1 to 3.5 – low level of ICP,
- from 3.5 to 7 – average level of ICP,
- from 7 to 10 – high level of ICP.

Out authors group proposes to calculate the magnitude of the *prospective capacity potential (PCP)* of company by the formula (3).

$$\mathrm{PCP} = \frac{LPFCP}{\sum PFCP} \qquad (3)$$

where *LPFCP* – strategic level of prospective factors of capacity potential, $\sum PFCP$ – sum of perspective factors of capacity potential.

As in similar cases, the optimal value of the indicator of the *prospective capacity potential* of company is taken as 100% or 1, since a priori under normal conditions the company owns and plans to own in the future 100%, that is, the overall potential of capacities and therefore the obtained value of the specified value must be compared with 1 or 100%.

Results of our studies confirm that magnitude of the *strategic adaptation of company (SAC)* makes it possible to determine how effective its current strategy is in the current economic conditions. We propose to study the degree of strategic adaptation by identifying the success factor of active strategy in future (*future success factor, FSF*) and current success factors of active strategy (*current success factors, CSF*) and evaluate them on a scale from 0 to 1, and then summarize the obtained results. Sums of values of current and future success factors of the current strategy are taken, respectively, as the levels of current strategy in the present and future. From the sum of success factors we propose to formulate variants of optimal corporate strategies, which in formula (4) are compared with the level of success of the current strategy. It should be noted that success factors are evaluated not accidentally, because success factors characterize future efficiency and are necessary for company's successful performance on the market. Success factor creates little or no negative impact, since it can be considered as the key to the continued corporative sustainability in emergent environment. Thus, the *degree of strategic adaptation* (*DSA*) of company according to each variant of the optimal strategy is calculated according to formula (4).

$$\mathrm{DSA}_i = \frac{\sum \mathrm{OS}_j}{\sum \mathrm{CFS}} \qquad (4)$$

where DSA_i – degree of strategic adaptation, where $i = 1, 2, 3, \ldots, n$, $\sum \mathrm{OS}_j$ – level of alternative options of optimal strategy, where $j = 1, 2, 3, \ldots, n$; *CFS* – level of current strategy factors.

The level of company's strategic adaptation is determined by comparing the degree of its strategic adaptation with the maximum possible amount of strategic adaptation, which we take for 10, because success factors as dimensions of strategy are rated on a scale from 1 to 10. Thus, the magnitude of the level of strategic adaptation of an industrial company we suggest to rank at low, average and high levels according to the proportional distribution of their importance within following scale, the range of which covers 100% assessment of strategic adaptation:
- from 1 to 3.5 – low level of DSA,
- from 3.5 to 7 – the average level of DSA,
- from 7 to 10 – high level of DSA.

The indicator of the *perspective level of strategic business units* (*PLSBU*) characterizes the degree of effective using of given *SBU* as one of the market sectors within company's strategic business-unit's set. We propose to calculate the overall level of perspective of each *SBU* according to formula (5).

$$PLSBU = OSF_{sbu_n} + CTC_{sbu_n} + TLFA_{sbu_n} \qquad (5)$$

where OSF_{sbu_n} – overall strategic flexibility of SBU, CTC_{sbu_n} – current total contribution of this SBU to overall synergism level of company's SBU, $TLFA_{sbu_n}$ – total level of future attractiveness of SBU.

It is generally known that the process of a company's strategic business-unit's set formation is carried out on the basis of the results of each individual SBU research. In accordance with the magnitude of the overall level of prospects of each SBU, the most promising of them are chosen for further company's strategic business-unit's set formation. The total level of prospects for company's strategic business-unit's set is calculated by summing the values of the overall level of prospects of those SBU that were part of it.

In other words, the strategic potential of company's success is a proportional combination of the potential of its internal capacities with the potential of its market opportunities, which provide the company with the efficiency of applying the corporate strategy in conditions of its economic environment. Accumulation of strategic potential of success is carried out by accumulation of potential of internal capabilities considering company's market capabilities and the level of its strategic adaptation on the market.

In accordance with authors' opinion, evaluation of the strategic potential of company's success involves a total assessment of its internal capabilities, characterized by the level of its strategic adaptation and the level of prospects of company's strategic business-unit's set, which are adjusted by the ratio of potential capacity estimation of company as a whole.

4.2 Method of estimating the company's competitive status

It is necessary to underline that the method of estimating competitive status reflects company's competitive position in the market. The mathematically company's competitive status is the product of such values as the required level of investment (the current level – to determine the current competitive status, the planned one – to determine the future competitive –status), and the value of capacity standard, and the value of potential of success.

Evaluation of the company's competitive status is based on the strategic potential of success and the value of the current volume of real investment; the data are taken from the company's financial statements. The magnitude of a company's strategic success characterizes the overall level of its strategic capacities that is necessary to achieve break-even activity. The value of current volume of real investments characterizes the level of company's financing of current and non-current assets in order to expand its market capacities and increase its competitiveness.

We propose to calculate the magnitude of company's competitive status by the formula (6).

$$CS_{comp.} = SPS_{comp.} \times V_{r.inv.} \quad (6)$$

where $SPS_{comp.}$, $\%$ – company's strategic potential of success, $V_{r.inv.}$, $\%$ – volume of real investments in the current period, which is expressed as a percentage of the maximum amount of company's real investments.

The optimal value of company's competitive status is 100%, since a priori under normal conditions the company has a 100% level of competitiveness on the market. Therefore, in order to determine the magnitude of company's competitive status under the given conditions, it is necessary to compare this value with the optimal value, i.e. to divide by 100%. Then the magnitude of company's competitive status can be characterized according to the following scale:
- from to 33.5% – low CS,
- from 33.5% to 70% – average CS,
- from 70% – high CS.

According to our beliefs, one of the most important strategic goals of a company that hopes to succeed is the transformation of market-relevant competencies into market competitive advantages. As a result of this process, the company is able to accumulate strategic success factors that shape the company's sustainable competitive status. Thus, transformation of the strategic potential of success and of the company's management, because such transformation aspects of competitive status into factors of success is the task is one of the leading strategic goals of the company, i.e. basic formation of company's sustainability.

5 Conclusions

Research of corporate sustainability provides for the account of emergence and volatility of unpredictable environmental factors. However, the reactive emergence of the company itself is able to overcome the possible negative effects of market volatility, since the emergent reactions of the company are manifested in the form of mobilization of fundamentally new strategic resources and opportunities to operate under uncertainty. Each company should include the results of forecasting a certain set of standard and non-standard emergent environmental challenges in the corporate strategy development process. Accordingly, in period of economic crisis and pre-crisis periods, the effective company's managers initiate the launch of a prearranged set of emergent reactions to unexpected "external challenges" [19].

The practical activity of successful foreign engineering companies such as the American corporations Ford Motors, General Motors, European concern PSA (France), Volvo (Sweden), Volkswagen (Germany) and international alliances such as Renault-Nissan-Mitsubishi (France-Japan) can hold the leading strategic positions in the volatile, highly competitive global automobile market, thanks to sometimes non-standard strategic decisions and, at the same time, flexible corporate strategies.

In particular, we consider the decision to create an operating board of the Renault-Nissan-Mitsubishi Machine-Building Alliance, as successful example strategic sustainability, which can completely control the alliance's activities, that "will be a major factor in the Alliance's "new start" and facilitate operational

cooperation between companies and at the same time can help in finding new ways to make profit for their shareholders and employees" [20].

According to author's point of view, the strategic leaders of the global automobile industry provide advantageous strategic positions on the basis of corporate sustainability approach, i.e. the effective usage of strategic potential of success to solve economic problems, the principal of which are increasing of profitability and strengthening of market position.

Thereby, the key aspect of strategize company's sustainability management is considered by the authors to be the transformation of the strategic potential of success and aspects of competitive status into factors of success it is necessary to take into consideration all the peculiarities of environment emergent influence on of company's activity. Thus, company's sustainability management methods, including the level of its strategic potential of success, should take into consideration the limitations of company's influence on market potential.

It is necessary to remember that any organization is located and functioning under the influence of emergent environment, therefore, every action of all organizations without exception is possible only if the environment permits its existence. That is why the main task of the business entity when choosing the methods of managing the strategic potential of success is the thorough strategic analysis of the market environment in particular, macro-environment, direct environment and the internal environment. In this case, it should be underlined three main systems necessary to solve company's sustainability tasks connected with accumulation of potential of success. Such systems include: strategic planning, implementation and control. These systems are respectively responsible for the development, implementation and revision of current strategy; complex application of the systems in the process of company's sustainability management provides the development of its successful strategy in future.

In this account we'd like to note, that the researches of our group in the field of company's potential sustainability are in the development process. The next stage will be its practical penetration into company's activity and several regional business entities have already confirmed their participation in mutual investigations. We suppose that manufactured application of proposed *Methodology of evaluation of company's sustainability potential* would assist the company's successful division.

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Optimization of economic and environmental factors of the logistic system of enterprise management

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Abstract. The purpose of the study is to develop an economic-mathematical model of the socio-economic system, which takes into account its logistical structure and ecological viability. This allows for optimal budget planning for the new project. The methodology of the study is based on the method of J. Forster, who proposed to consider the logistics system of any enterprise as a system of reservoirs linked by material, financial and information flows. The main result of the study is as follows. The methodology is designed and developed a mathematical program that allows estimating the relative value of fixed assets of production and the number of costs for creating a retail network with the impact of the environmental components. It is shown that this ratio is determined by the value of all key parameters of the enterprise logistics system. This result was obtained through careful modeling of structural changes in the logistics system of the enterprise. All basic communications (flows) between the elements of the logistics system were also considered. Calculations were conducted for the system of the equations which have been written down in shape with discrete-time. At the same time modeling was carried out so that there were no "not physical" phenomena (such as overflow of warehouses, etc.). As a result of calculations, optimum values for all basic characteristics of the new project have been specified. The most actual has separately been considered for practice as a case of optimum planning of storage facilities. The practical importance of research consists that scientific representations about interrelation of the capacity of the enterprise with key parameters of the logistic system can form a basis for more effective planning and management budgetary and production processes at the enterprise, namely: it is more reasonable to plan scales of production and expenses on logistics creation.

1 Introduction

Despite the extensive literature on designing and management of logistic systems (LS) [1-11] in the scientific literature shortage of models which would describe all links LS within the limits of uniform system of the equations is felt. General difficulties arise with identification of models. Shortage of the information leads to essential errors in the justification of models. Articles [1, 2] provide the literary review in the discrete modelling of events describing a difficult supply chain. Models allow to study dynamics of a supply chain, to develop and compare alternative strategy.

Work [3] marks now the global and expanded markets should process and manage more and more differentiated products, with shorter life cycles, and consumer delivery periods are reduced by low volumes.

The requirement for more careful management of LS increases in such conditions [4]. Models LS should be created for this purpose [5-7]; it is necessary to consider factors of destabilization which reduce reliability, stability and efficiency of logistic processes [8-10]. The author of work [11] confirms risks of supply and demand it is necessary to consider.

Article of authors [12] offers model which, from the moment of representation, meets established to requirements. This model allows taking into consideration detailed features of the market. But at the same time, the model has a lack; it leads to stable solution in a broad range of parameters.

Authors Y. Sherstennikov and T. Rudjanova [13] have offered a method to eliminate this defect. This method is based on averaging of rates of sales and transportations of the goods on a certain time distance. Till now there are no effective methods to plan an advertising campaign in real time of the enterprise, in view of logistics of the enterprise and a market demand for products.

The purpose of develop economic-mathematical model of LS the enterprises for tasks of optimization of new projects and management the LS.

The researchers conducted before [1-12] studied only some certain functions of the LS. The presented approach differs that it covers all chain from production

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to delivery to an ultimate consumer. The paper [13] is not considered the ecological viability.

2 Presentation of the basic research

The basic results of research. Investors plan to create the new enterprise with a complete cycle from production of the goods before delivery of the goods to the consumer. The scheme enterprise logistics should correspond to the scheme presented in Fig. 1.

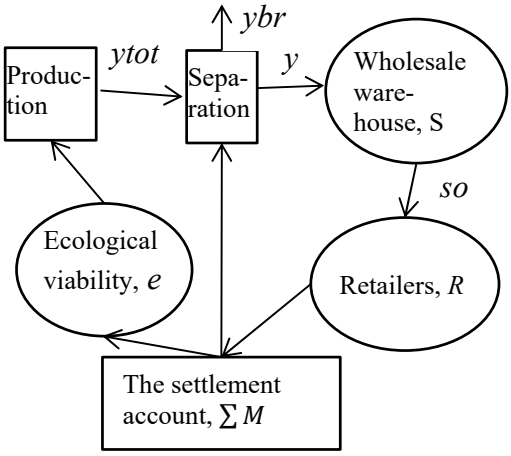

Fig. 1. Scheme of the enterprise's logistics.

It is supposed that the enterprise will be completely provided by raw and circulating assets.

Investors give the task to managers to calculate optimum parameters of all links of the LS when known technological parameters of production.

Time will be treated as a discrete variable i $(i = 0, 1, 2, \dots, T)$. We will analyze the project of the T length (the planning horizon). Let us assume that the influence of advertising on the potential current demand Q_{i+1} in the $(i+1)^{\text{th}}$ period is described by the formula:

$$Q_{i+1} = Qr(Z) * \left(1 - \exp\left\{-\frac{i}{t}\right\}\right) + Qn(p), \qquad (1)$$

where $Qn(p)$ represents the value of potential demand that depends on the price for the product (p) in the absence of advertising; $Qr(Z) = Qm * \left(1 - \exp\left\{-\frac{Z}{tz}\right\}\right)$ is the maximum value of additional potential demand due to advertising; t and tz are the parameters of lagging; Z – number of advertising shares in a current of one period (day).

Formula (1) means that the impact of the advertising campaign Q_i on the potential demand is described by the first-order lag model [7, 8]. In the absence of advertising, the potential demand for the product is determined only by its price $Qn(p)$.

We suggest the linear dependence of the impact of advertising $Qn(p)$ on the price:

$$Qn(p) = Qn + kq * (p0 - p)$$

where Qn is the value of the potential demand at the price $p0$.

Let us formulate the system of equations that describe the logistics system of the enterprise depicted in Figure 1. We will assume that the company is fully provided with working capital.

1. The change in the demand Q_i for products on the market is an input impact for the enterprise whose task is to bring its output in line with the demand.

$$r_{i+1} = n \cdot R_i \cdot (Q_i - V_i) \qquad (2)$$

where n is the sales rate of goods (units per time period) in the ith period; R_i is the inventory level (quantity od goods) at the retail in the ith period; V_i is the inventory level in the hands of the consumer (not consumed yet).

2. Quantity of goods (inventory level – using the terminology of J. Forrester) at the retail R_i is determined by the recurrence formula:

$$R_{i+1} = R_i + Td \cdot (so_i - r_i) \qquad (3)$$

where so_i is the rate of delivery (units per week) from the warehouse to retailers; Td is the period of discretization of the model (the time interval between solution).

3. The level R_i should be within the limits $0 \le R_i \le Rm0$, where $Rm0$ is the maximum possible inventory level at the retail. The requirement is described by the following formula for the rate of delivery from the wholesale warehouse to retailers:

$$so_{i+1} = min\left[r_i \cdot \left(1 + \frac{Rm0 - R_i}{Rm0}\right), \frac{Rm0 - R_i}{Td}, \frac{S_i}{Td}\right], \qquad (4)$$

where S_i represents the inventory level at the wholesale warehouse.

Publication [5] substantiates the need for averaging in performing the calculations with the proposed model:

$$\overline{so_i} = \langle so \rangle_{i-ps}^{i},$$

where ps is the averaging time interval.

4. The production rate y_i is determined by the following formulas:

$$y_{i+1} = \left(y_i + \frac{ym - y_i}{ty}\right) \cdot A(S_i), \qquad (5)$$

$$A(S_i) = \begin{cases} 1, if\ S_i < qS \cdot S_m, \\ \frac{qS \cdot S_m}{S_i}\ otherwise, \end{cases} \qquad (6)$$

where y_i is the production capacity in the ith period; ym is the planned value of production capacity; Sm is the maximum inventory level at the wholesale warehouse. These formulas allow avoiding the overflow of the wholesale warehouse.

Planned the production capacity ym is determined by balance cost of the basic production means (BPM) K, which can be presented in the form of the sum such composed $\mathrm{K} = \mathrm{K}^{(\mathrm{dc})} + \mathrm{K}^{(\mathrm{mr})} + \mathrm{K}^{(\mathrm{e})}$, where $\mathrm{K}^{(\mathrm{dc})}$ is BPM on which a damage control is producing, $\mathrm{K}^{(\mathrm{mr})}$ is BPM not corresponding modern safety requirements of ability to live and them need to replace; $\mathrm{K}^{(\mathrm{e})}$ is effectively used BPM. Thus, it is possible to write down:

$ym = f \cdot K^{(e)} = e \cdot f \cdot K$ (f is capital productivity), where the parameter e determines a share of BPM, which effectively used ($0 < e < 1$). We will notice that damage control, and also current modernization of the equipment is carried out at the expense of money funds from the enterprise current account (see Fig. 1).

5. The inventory level at the wholesale warehouse S_i is calculated using the following formula:

$$S_{i+1} = S_i + Td * (y_i - so_i), \quad (7)$$

where y_i is the rate of goods flow which goes into the wholesale warehouse from the production.

6. To determine the net profit of the enterprise, the following formula is applied:

$$M_i = (1 - kp) \cdot [(1 - kad) \cdot p \cdot r_i - p \cdot c \cdot y_i -$$

$$-k2 \cdot S_i - z \cdot Rm - qz \cdot Z] - B(y_i) + C(S_i), \quad (8)$$

$$B(y_i) = \begin{cases} 0, if\ i, < 1 \\ qy|y_i - y_{i-1}|, otherwise \end{cases},$$

where c is the share of the prime cost in the price for products; p is the price for a production unit; $k2$ is payment per one period of the storage of a product unit at the wholesale warehouse; kp is the income tax rate; kad is the value-added tax rate; qy is the cost of 'including', 'excluding' a unit of production capacity, qz is a cost of one advertising share.

The formula (9) provides inadmissibility of overflow of a wholesale warehouse. Composed it is added with that end in view. These are modelling "penal sanctions" for overflow wholesale warehouse:

$$C(S_i) = \begin{cases} o, \ if\ S_i < Sm \\ -S_{st}, \ otherwise \end{cases}, \quad (9)$$

3 Construction of the investments plan

Investors (the administration also) plan to create the new enterprise having for this purpose the budget at a rate of monetary units. All means it is planned to spend on two articles: acquisition of the basic production means (B1) and creation of a retail network of trade (B2). Premises for a wholesale warehouse are supposed to be leased. Carrying out of a permanent advertising campaign is planned also, but means for an advertising campaign should be allocated from current profit. Thus:

$$B = B1 + B2. \quad (10)$$

Expected life expectancy of the project is *T*. Then it is possible to write down such ratio

$$p \cdot \sum_{i=1}^{T} y_i = f \cdot B1, \quad (11)$$

where f is capital productivity from the project, for profitable projects *f* is within the framework (2; 4) (the top limit is an optimistic estimation).

For an estimation of planned capacity (productivity) ym of the enterprise it is possible to use the approached formula – $\sum_{i=1}^{T} y_i = T \cdot ym$, then from the formula (11) it is found

$$ym = \frac{f \cdot B1}{p \cdot T}. \quad (12)$$

At planning the retail managers of the enterprise recognize that at creation of areas the retail for placing of one commodity unit it is necessary to spend (on the average) g monetary units. Then allocated budget will be enough for placing in shops the retail

$$Rm = \frac{B2}{g} \text{ (commodity units).} \quad (13)$$

Here is maximum capacity of the retail. As variation parameter will be $B1$, that Rm is actually defined from a relation:

$$Rm = \frac{B - B1}{g}. \quad (14)$$

Let's solve following tasks consistently.

Task A): at a preset value of the price p of a commodity unit and in the absence of an advertising campaign ($Z = 0$) to find cost of the basic production means ($B1$) at which the maximum profit on the project will be got:

$$F1(B1) = \sum_{i=0}^{T} M_i \to max. \quad (15)$$

Task B): considering parameter p as variation in the absence of an advertising campaign, we must find cost of the basic industrial means ($B1$) and of the goods price at which the maximum profit on the project will be got:

$$F1(B1, p) = \sum_{i=0}^{T} M_i \to max. \quad (16)$$

Task C): as variation parameters it is accepted both the commodity unit price p, and quantity of daily advertising shares Z (which it is considered to constants). Thus, the mathematical task of optimization of the project is formulated as

$$F1(B1, p, Z) = \sum_{i=0}^{T} M_i \to max. \quad (17)$$

Restrictions for tasks (15) - (17) there are both the equations of model (1) - (8) and an obvious condition:

$$0 \le B1 \le B.$$

We choose such units of measure. As a monetary unit, it is accepted a hundred dollars US (100 USD). Levels we will measure in units (quantity of the goods/raw materials), for rates we use the unit (quantity of the goods/raw materials per day).

The solution of problems (15) - (17), at the specified restrictions, we search at following values of technological parameters (the parameters of model):

$$t = 10, Qm = 2000, zy = 20, tz = 30, kq = 100,$$
$$p0 = 48, qS = 0{,}88, n = 1{,}6 * 10^{-5}, Td = 1,$$
$$kp = 0{,}3, kad = 0{,}06, c = 0{,}5, k2 = 0{,}03,$$
$$z = 0{,}05, qz = 0{,}6, qy = 100, f = 3, T = 365,$$
$$g = 150, S_{st} = 1500 \quad (18)$$

Fig. 2 illustrates the optimum solution of C) problem.

The solution of an optimizing task (15) it has been found at such values of the fixed parameters: $p = 50$, $Z = 0$ i.e. the price of goods is 50 monetary units; advertising was considered as the absent. At the solution of an optimizing task (16) advertising also was considered as the absent. Solution of the tasks of optimizing (15) – (17) it is then possible to present in the form of the table 1.

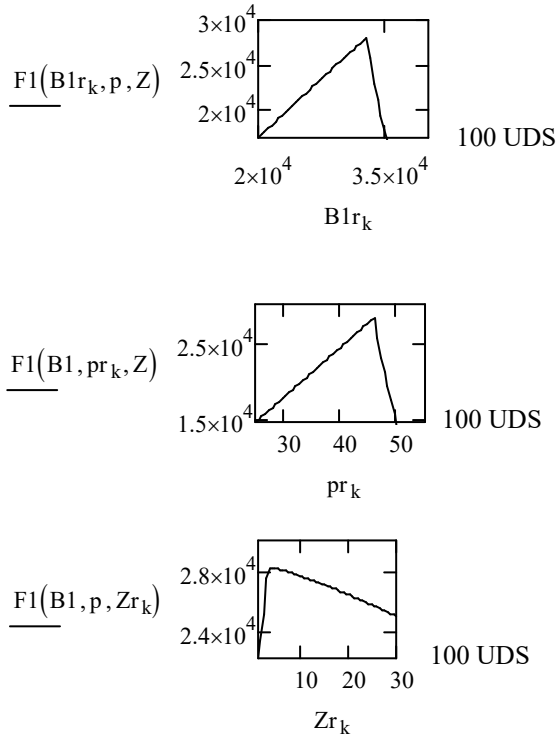

Fig. 2. An illustration of the optimum solution of problem C).

Table 1. Parameters of optimum solutions.

Problem	$B1$	p	Z	ym	Rm	$F1$
A)	25011	50	0	4,28	99,9	21239
B)	32429	45	0	5,55	50,5	27313
C)	32954	46,2	3	5,64	46,97	28113

From the table it is visible that at increase in number of variation parameters the economic result $F1$ of the project increases. This result is quite natural.

Let's analyze an optimum solution of C) problem. Considering that for optimum a problem C) solution is $B1 = 32954$, from formulas (12) and (14) it is discovered

$$ym = 5{,}64,\ Rm = 46{,}97 \qquad (19)$$

Relations (12) and (14) solve a problem of definition of best values of key parameters of logistics system at the set budget ($B = 4 * 10^4$), namely: the basic industrial need to be spent means for acquisition $B1 = 32954$; the retail it is necessary to spend for creation $B2 = 7046$. Thus, optimum capacity will be $ym = 5{,}64$, optimum capacity of the retail will be $Rm = 46{,}97$, the optimum price of a commodity unit will make $p = 46{,}2$ (see table 1), optimum intensity of an advertising campaign will make $Z = 3$ (actions per day).

4 Optimization of logistics system of the enterprise

Planning the price policy taking into account association of demand on the price of the goods, a management guarantees with managers to solve the following optimizing problem. As target function of a problem of optimization, the profit which will be received for planned time of life T (the planning horizon) of project is chosen:

$$F_T(ym, p, Rm, Sm, Z) = \sum_{i=1}^{T} M_i \to max. \qquad (20)$$

Variation parameters of an optimizing problem (20) are: maximum productivity ym, the goods price p, maximum capacity Rm of a web of retail trade, maximum capacity of a wholesale warehouse Sm and a publicity expense Z. System of restrictions for an optimizing problem (20) is the set of equations (1) – (8). All enumerated parameters are included into system of the interconnected equations (1) – (8) which describe functioning of the LS of the enterprise. Therefore best value of these parameters should be received within the framework of one optimizing problem.

Optimizing problem (20) it is solved at following values of parameters:

$$Rm = 80,\quad qy = 100,\quad Q = 1200,\quad n = 0.0001,$$
$$k1 = 0.33,\quad k2 = 0{,}01,\quad So = 100, Sm = 200,$$
$$Ro = 50, n1 = 0{,}1,\quad qS = 0{,}88, kp = 0.25,$$
$$kad = 0{,}06, kS = 0{,}5, c = 0{,}6, p = 10,\quad z = 0.01,$$
$$Se = 180,\quad qy = 50. \qquad (21)$$

The following solution of an optimising problem has been discovered.

$$\begin{pmatrix} ym_opt \\ p_opt \\ Rm0_opt \\ Sm_opt \\ Z_opt \end{pmatrix} = \begin{pmatrix} 6{,}16 \\ 48{,}36 \\ 76{,}19 \\ 50{,}05 \\ 50{,}9 \end{pmatrix}, \qquad (22)$$

$$F_T(ym_opt, p_opt, Rm_opt, Sm_opt, Z_opt) = 16727. \qquad (23)$$

Let's become clear a reason of an optimality of a solution (22), (23). Key parameter defining full profit F_T is capacity ym. Let $ym < ym_opt$, for example $ym = 6{,}0$, remaining parametres are defined under the formula (22). Then calculation gives value $F_T = 16056$. It is less than outcome of an optimum solution (23). Let $ym > ym_opt$, for example $ym = 6{,}26$. Now calculation gives value $F_T = 1418$. It is much less than

optimum solution. Fig. 3 illustrates a reason of such reduction.

S_i - current level of the goods in a warehouse;
Sm – maximum level of the goods in a warehouse.

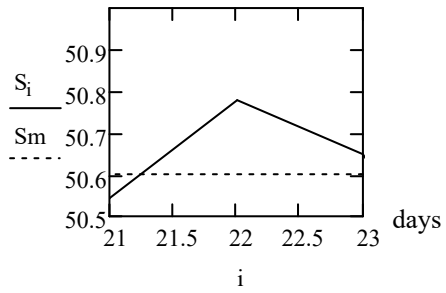

Fig. 3. Behavior of level of the goods in a wholesale warehouse at $ym = 6{,}26$.

From Fig. 3 it is visible that at phase 21 "penal sanctions" come into effect. Overbillings of a wholesale warehouse can be avoided if more rigid restrictions on capacity in the formula (7) to superimpose, having reduced factor qS from value 0,88 to 0,87. Thus for $ym = 6{,}26$, the value $F_T = 16426$ has been received. It also is less than best value (24).

Above the problem only concerning a capacity modification has been investigated. However, there is still a possibility of a scale modification of all parameters. Let the parameter is factor defining scale transformation of all parameters of the LS: $X^* = qm \cdot X$ where X is any of parametres in the left part a relation (22). Then it is possible to present association of economic outcome $F1$ on scale factor in the form of table 2.

Table 2. Association of the economic outcome on scale factor Costs for environmental protection and security.

Scale factor, qm	Costs for environmental protection and security (min-max)	Economic outcome, $F1$
0,95	723,35-2893	14467
1	836,35-3345	16727
1,004	819,7-3279	16394
1,008	56,85-227,4	1137

From table 2 it is visible that there is a certain scale of manufacture at which the economic outcome is maximum. It is obvious that this scale is set by an amount of potential customers of production Q.

Let's make the analysis of the received optimum solution (22), (23). For this purpose we will calculate dynamics of performances of the LS on the basis of a set of equations (1) – (8). Outcomes of calculations (at values of parameters (21)) are shown in Fig. 4 – Fig. 7.

Dynamics of basic rates of the LS is shown in Fig. 4. From figure it is visible that near to 100 periods all rates leave on value.

Equalization of rate of sales with rate of deliveries of the goods in retail trade (Fig. 4 see) results, according to the formula (4), to stabilization of quantity of the goods in the retail. It is visible from Fig. 5.

r – rate of sales of the goods;
so – rate of deliveries at the retail;
v- rate of production.

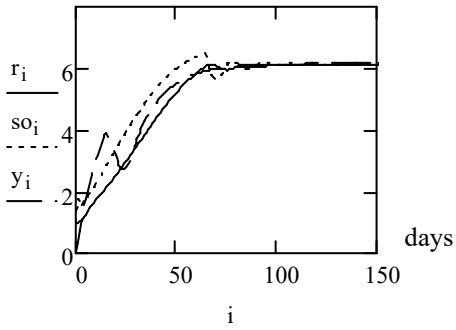

Fig. 4. Time dependence of basic rates of the LS.

R_i – current level of the goods in retail;
Rm0_opt – maximum level of the goods in retail.

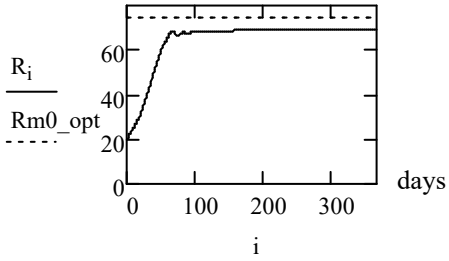

Fig. 5. Dynamics of level (quantity) of the goods in the retail.

S_i – current level of the goods in a warehouse;
Sm – maximum level of the goods in a warehouse.

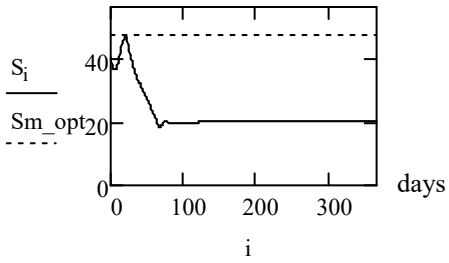

Fig. 6. Dynamics of level (quantity) of the goods in a wholesale warehouse.

It is important that goods level in the retail R_i is close to the maximum capacity the retail (i.e. to contractual level $Rm0_opt$), but in any period does not surpass a maximum level. That fact that R_i is close to $Rm0_opt$, provides high rates of sales of the goods (see the formula (2)). This conclusion is quite clear.

Dynamics of level of the goods in a wholesale warehouse is shown in Fig. 6. That fact that goods level is stabilized near to the period 80 follows from Fig. 4. By the period 80 rates of production y_i and deliveries in the retail so_i become equal.

Let's notice that stabilization of level near to the maximum (contractual) stock of the goods in a network of retail trade which has been specified as a result of the

solution of an optimizing task, is one of the basic conditions of effective work of the LS.

The sharp peak of stocks of the goods in a wholesale warehouse in the beginning of work which is observed in Fig. 6, can be explained with the help Fig. 7. From the formula (8) it is clear that during those periods, in which $y_i > so_i$ stocks increase, and on the contrary.

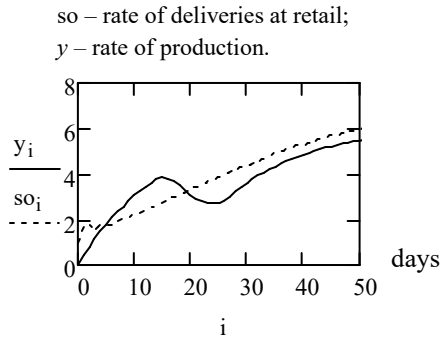

Fig. 7. Time dependence of rates of the goods imported on a wholesale warehouse (y_i) and rates of the goods exported from a wholesale warehouse (so_i).

Fig. 7 shows stocks in a wholesale warehouse grow up to the period 20, then start to decrease. From Fig. 8 it is visible that goods stocks on hands at consumers are stabilized almost at the same level, as stocks in a wholesale warehouse.

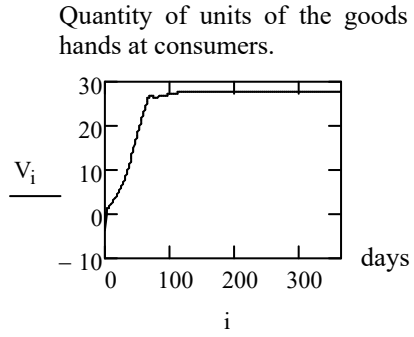

Fig. 8. Dynamics of level (quantity) of the goods on hands at consumers.

Fig. 9 shows dynamics of current profit of the enterprise for optimum solution. The current profit is negative work in initial stages. Such behavior of current profit is characteristic for an initial stage of work of any project. To understand why negative values of profit take place in our case, we will consider Fig. 10.

From the formula (9) it is visible that current value of profit of the enterprise basically is determined by a ratio of rates of production (y_i) and rates of sales (r_i). And sales of the goods bring the positive contribution, and goods production brings the negative contribution to profit (that is quite clear). In Fig. 10 the first 50 periods of work of the enterprise are shown. From drawing it is visible that during the first 20 periods (days) of work rate of production of the goods essentially exceeds rate of realization. It also leads to negative values of profit during these periods.

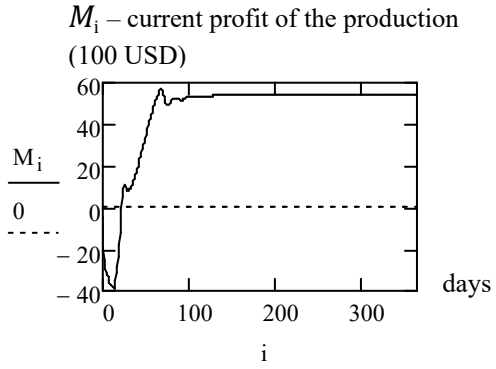

Fig. 9. Dynamics of current profit of the enterprise.

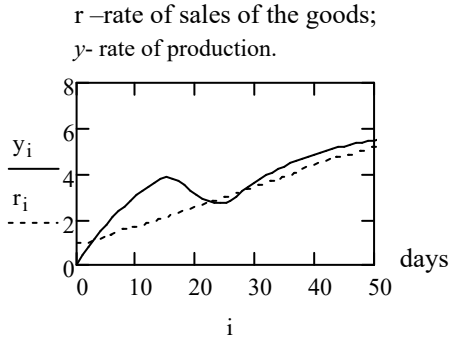

Fig. 10. Time dependence of rates of production (y_i) and rates of sales (r_i).

5 Co-optimization of a warehouse of finished goods and a retail trade network

The crucial role in logistics is played by storage facilities. Raw, having reached productions it is transformed to semi-finished products, and then in finished goods. Then, in a warehouse the finished goods are transformed to stocks or the collected customer orders. Customer orders, in turn, are transformed by means of a retail network of trade to money funds when there are at the end user.

At development of the project of logistic system of the enterprise, capacity and goods price can be set in advance (i.e. are exogenous parameters). Thus, the designing task will be reduced to an optimum choice of volumes of a wholesale warehouse and a retail trade network.

Statement of an optimizing task is a similar task (20) but with smaller quantity of variation parameters:

$$F_T(Rm, Sm) = \sum_{i=1}^{T} M_i \to max. \qquad (24)$$

Optimizing task (24) it is solved at such values of parameters:

$Rm = 56,\ qy = 100,\ \mathrm{Q} = 1000,\quad \mathrm{n} = 0.00005,$
$\mathrm{k1} = 0.33,\ k2 = 0{,}01,\quad So = 50,\ Sm = 103,$
$Ro = 40,\quad n1 = 0{,}1,\quad qS = 0{,}88,\quad \mathrm{kp} = 0.25,$
$\mathrm{kad} = 0{,}06,\quad kS = 0{,}5, \mathrm{c} = 0{,}6, \mathrm{p} = 10, \mathrm{z} = 0.05,$

$$Se = 180, \quad qy = 50. \tag{25}$$

The solution of an optimizing task (24) is the such:

$$\begin{pmatrix} Rm0_{opt} \\ Sm_{opt} \end{pmatrix} = \begin{pmatrix} 64{,}7 \\ 125{,}8 \end{pmatrix}, \tag{26}$$

$$F1(Rm0_{opt}, Sm_{opt}) = 15717.$$

Consider dynamics of the basic economic characteristics for received solution. We will consider only initial stages before stabilization of counted characteristics. Fig. 11 shows that all rates become equal by 70 period of work of the enterprise.

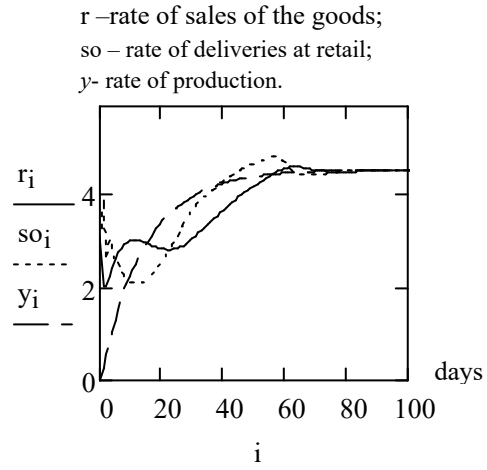

Fig. 11. Dynamics of the basic rates for optimum solution which is described by the formula (27).

That fact that rates become equal among themselves means stable work of LS. If it did not occur, the LS simply could not function as in this case would take a place or overflow of some storage facilities, or the goods stock was settled on some links of the LS. Fig. 12 shows dynamics of a stock of the goods in retail. We assume that in an initial stage retail trade is provided by a commodity output in number of 40 units and in a wholesale warehouse the finished goods stock constitutes 50 units.

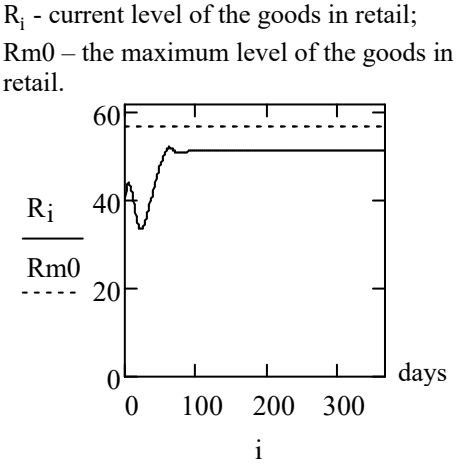

Fig. 12. Time dependence of a stock of the goods in retail.

Initial value of capacity it is considered equal to zero. These assumptions explain ratios of rates shown in Fig. 11 in work initial stages.

Fig. 13 shows dynamics of a stock of the goods at a wholesale warehouse.

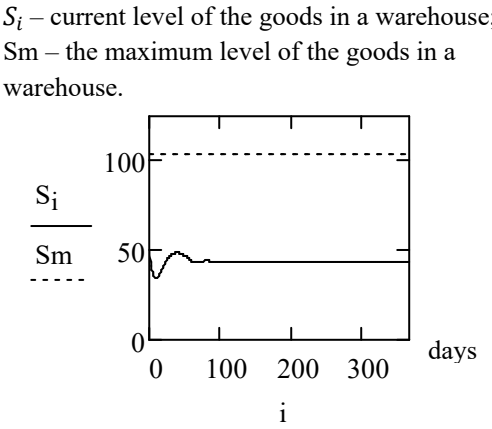

Fig. 13. Time dependence of a stock of the goods in a wholesale warehouse.

Fig. 14 explains behavior of a stock of the goods in a wholesale warehouse.

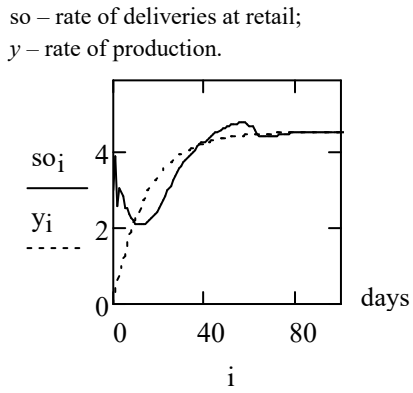

Fig. 14. Dynamics of the basic rates for optimum solution which is described by the formula (26).

Deliveries at retail during the first 8 periods reduce stocks in a wholesale warehouse because production has not time to recover them. Further to 30 periods deliveries in a wholesale warehouse from a production link dominate.

Fig. 15 shows dynamics of net profit of the enterprise for optimum solution which is described by the formula (26).

In a work initial stage considerable decrease is observed has beaten. Availability of such period characteristic is typical for any new project.

From the formula (9) it follows that the basic contribution to current profit of the enterprise is determined by a ratio of rate of sales r_i and rate of production y_i. Fig. 16 explains dynamics of net profit of the enterprise shown in Fig. 15.

Fig. 16 shows that at 100 periods the rate of sales becomes equal to the rate of manufacture; it leads to the stabilization of current profit. It is visible from Fig. 15.

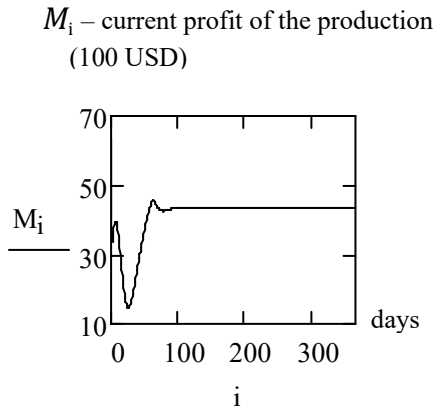

Fig. 15. Dynamics of net profit for optimum solution, which is described by the formula (26).

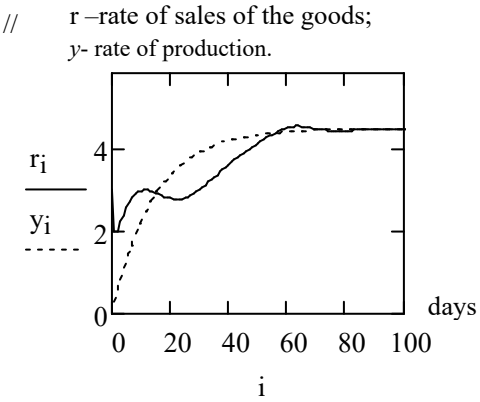

Fig. 16. Dynamics of the basic rates for optimum solution which is described by the formula (26).

6 Conclusions

The model of LS of the enterprise is developed. The offered model allows constituting the plan of capital investments for the new project. It is necessary to notice that plan development of investments is possible at detailed determination of characteristics of the project.

The developed model allows executing optimization of all key parameters of LS of the new project under conditions when the project budget is limited. The offered technique of optimization has allowed to specify values of all key parameters of LS of the new project taking into account budgetary restrictions, and also to calculate parameters of an advertising campaign and to specify enterprise price policy. Computations executed at set parameters of the LS have shown that from the complete budget of the project of 82,4 % should be spent for the creation of capacities and the others of 17,6 % on the creation of a network of retail trade.

Thus, the model of LS (1) – (9) allows to execute calculation of time dependence of all basic characteristics of LS that allows to manage all processes.

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Modeling the interaction between environment and the economy considering the impact on ecosystem

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Abstract. The problem of anthropogenic impact is becoming more acute every year. The basis of entrepreneurship is to maximize profits and increase profitability ratios. However, when calculating economic indicators, changes in the natural potential and the impact of any activity on the environment are not analyzed. In developed countries, more and more emphasis is focused on socially and environmentally conscious entrepreneurship, however, business is still predominant in the world, where the result of activity is an increase in financial resources due to environmental degradation. At the same time, there is an improvement in the situation with financing environmental protection activity. An increase of the population's consciousness is of a point-like nature, while the ecosystem continues to degrade. It is proved that the negative externalities that were described in the model by Pigou, Leontyev-Ford and others must be taken into account. The necessity of taking waste minimization and negative impact on the environment as a target function is justified. It is proposed to solve this problem systematically and to take into account the effect of the accumulation of negative implications of the impact on the ecosystem.

1 Introduction

The contemporary state of economic development is characterized by significant human interaction with the environment and a permanent change in the economic and ecological systems. Rapid dynamics and an increase in the links between influence factors become the reason for the emergence of new tools for managing and monitoring systems and is the driving force behind the implementation of new technologies and research methods. The economic condition of the state is described by macro indicators, which are expressed mostly in monetary value, while the environmental component and environmental impact are not taken into account in the calculation.

Population growth is one of the factors contributing to the emergence of many types of environmental stress. The role of the growing population is particularly evident in the fact that it is a major factor determining the need for increased food production. And with the expansion of production and the emergence of new goods, the number of gradually accumulating residues is increasing significantly. Most of all this problem is faced by developing countries that have not yet fully complied with environmental legislation, slow investment in the environmental sector and the introduction of the latest environmental technologies.

After the industrial landscape became a major economic and cultural presence in large cities, creating urban deserts and conversion of industrial into other functions necessary to take care of the natural component in order to be competitive at the European and global levels. Currently, the environment represents the ensemble of natural and artificial elements in which life evolves or the sum of the factors external to the human body such as: the atmosphere, the light, as well as all the other beings [1].

There is a link between the quality of life, living standards and the anthropogenic impact on the social and natural environment [2], because industrial facilities are extremely unequally distributed in the region. Industrial facilities are concentrated in cities and large settlements and provide a significant negative impact not only on the environment, but also create an uncomfortable living environment for the population. Regions of technogenic contamination with an extremely tense ecological situation are reinforced by a non-natural landscape. Currently, industrial facilities that have stopped their production activities are not enough investigated, but continue to provide a strong anthropogenic impact on the environment, since the disposal of industrial waste creates a tense ecological

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situation and poses a threat to the natural environment and population [3].

Many methods of investigation have been created to study the influence of man on the ecosystem, using the radiointerferometry technology of navigation satellite signals, it is possible to study ionospheric disturbances that move and are caused by large urban agglomeration [4].

An integrated assessment of the level of resistance of natural complexes to anthropogenic impact by detecting landscape factors of geosystems makes it possible to determine landscapes with different levels of stability potential (from relatively stable to weakly stable).

This requires various approaches in the development of environmental management structures, which the state should provide [5].

However, the modern ecology of the mining and processing industries is more economically oriented and it comes down to minimizing expenses and penalties for environmental damage. Mining enterprises are a source of anthropogenic cadmium entering the hydrosphere and soil. Cadmium can accumulate in plants and living beings, and then spread through food chains and adversely affect human health [6].

The ecosystem is exposed to constant negative impact also due to an increase in the amount of garbage as a result of human activity. The macroeconomic instability in Ukraine makes the garbage processing industry unattractive for investments, but with the help of tax incentives and taking into account the current level of salary in comparison with European countries, the situation can be improved [7].

Today, a model of a “circular economy” has been created, which offers to consider the impact of human activities on the environment, but this concept has been fully implemented in any country [8].

An ecosystem which is characterized by optimized consumption of energy and materials, minimal garbage generation and contamination and the use of any residues produced as raw material is considered to be highly effective. A key constituent of the interaction of environmental and economic components is to increase the efficiency of resource usage with the help of circulating materials and to minimize negative impacts, including from the accumulation of garbage from any activity.

2 Materials and methods

The garbage problem accompanies Ukraine throughout all the years of existence, however, the problem arose much earlier in the years of the planned economy and independent Ukraine, as a result, there were many both household and harmful industrial wastes. Alongside with the growth of the economy, population and consumption sphere, there is a rapid increase as volumes as types of waste, primarily industrial, household, and more recently, in particular, waste electrical and electronic equipment, batteries, used tires, vehicles, etc. However, I consider that Ukraine received from the planned economy a significant amount of waste that had been accumulated on its territory for many years due to an ineffective economic policy and thanks to the unresolved issue of waste management to independence. The main prerequisites for the development of the waste management industry are shown in Fig. 1.

As fig. 1 shows all the prerequisites for the development of the recycling process are significant, socially and environmentally-economically justified. The diagram does not present one more powerful socio-economic factor – the desire of the population to use an environmentally safe external environment, and hence, according to the Hicks theorem, bear the expenses of improving the environment [10]. In the last few years, the population or enterprises have been paying money to restore the environment, which has become another impetus to the development of waste disposal. The accumulated funds can be spent on the development of this industry and the introduction of new technologies. In developed countries, in general, these payments are larger, a better waste audit system, which contributes to the creation of more environmentally friendly production, the introduction of recycling, while undeveloped countries and developing countries have a lower environmental tax burden and are not able to develop independently the recycling sector without attracting investors. This is reflected in disposal methods, where recycling predominates in developed countries, while dumping of wastes is more preferable in less developed countries [11].

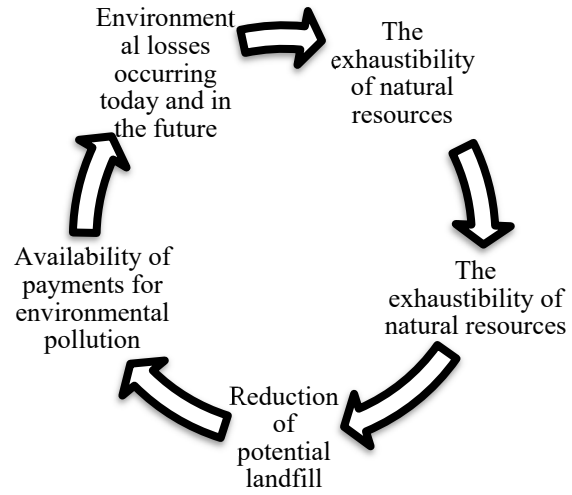

Fig. 1. Prerequisites for Waste Disposal [9]

The composition of household waste differs in different countries and regions, and that’s why the methods of disposal through the specifics of the region, legislative support for the use of sorting and recycling differ. Only a small part of garbage is recycled in Ukraine (Fig. 2), and this leads to the constant accumulation of garbage and environmental contamination.

As it is seen on fig. 2 the amount of household waste is growing alongside with a growth in living standards of population. In the days of political and economic crisis caused by the 2014 revolution, which caused inflation and a decrease in demand for products, there is a slight reduction of the rate of accumulation of waste (by 3,753 thousand tons), while with the stabilization of the economy, the quantity began to grow again to almost 12 million tons in year. The most influence of the economic crisis was experienced by waste management, which fell from 9,4 to 3,8 thousand tons. That's why scientists can conclude that the percentage of disposed waste depends on the economic condition of the country and is directly proportional to its gross domestic product.

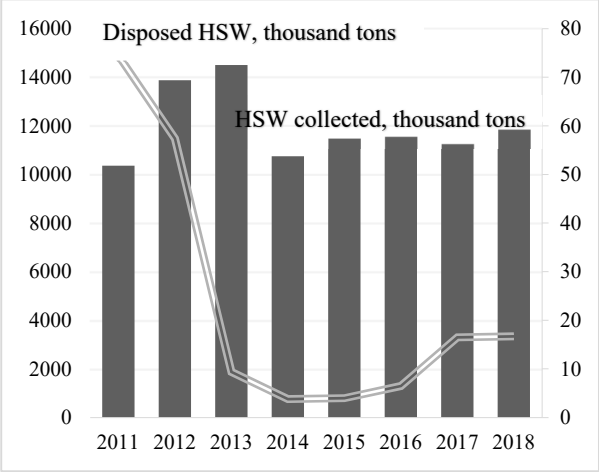

Fig. 2. The Management of Household Waste on the Time Interval in Ukraine [12]

V. D. Parondzhanov concluded that at the first stage of its existence, the GNP indicator adequately reflected the volume of goods and services produced and therefore could indeed serve as an indicator of wealth. But over time, the situation has changed. The rapid growth of population, even faster rise in consumption, depletion of natural resources, increasing the burden on the environment caused the emergence of new and unexpected problems. There was a need to spend significant funds on so-called corrective measures aimed at combating resource depletion, environmental pollution, various disasters, losses, and addressing acute social problems [13].

As a result, the planetary scale has changed in the bowels of the economy, which, however, has gone unnoticed by most economists, let alone the Heads of State and Government. The crux of the change is that a fundamentally new type of expense has emerged and has grown, called "corrective action expense."

3 Results

Analysis of the current environmental monitoring system in Ukraine shows that it has not yet become an important tool for effective environmental quality management, timely warning of the harmful effects of pollutants on the air, water, soil, health and well-being of the population, as well as public awareness. on the state and trends of environmental change.

The current state monitoring system only partially provides accurate and reliable quantitative information on the current levels of harmful or potentially harmful substances in the environment. The main purpose of the current monitoring system is not to minimize management measures to protect, preserve and restore the quality of the environment.

In O. Korzhevskaya's work, a modification of the Leontief-Ford dynamic model was proposed, which, in addition to the main indicators, takes into account the release of pollutants during the main and ancillary production, the cost of maintenance of emissions under the Kyoto Protocol, and pollution arising from consumption of products. This technique is one of the foundations of production in our opinion and takes into account the production waste and the impact on the environment [14].

The concept of "Zero waste" [15] should become the basis for the development of society where the profit would be calculated in all branches taking into account the expenses aimed on returning the external environment to its original state.

The target function of the green model is as follows:

$$F_1(x) = \sum_{i=1}^{n} x_i \rightarrow max; \quad (1)$$

$$F_2(y) = \sum_{i=1}^{m} y_i \rightarrow min; \quad (2)$$

where x_i – is the amount of profit on the sale of goods, and y_i – the sum of negative externalities, which must be reduced to zero to neutralize business activity. That is maximize the product in n sectors and minimize waste coming into being in the production process.

Pigou's theory of public welfare is the basis for a rational environmental management approach. According to this theory, environmental pollution is regarded as externalities. The essence of this term is that the market mechanism does not transform the external costs borne by society from pollution into internal costs of production, which is not reflected in the prices of products of polluting enterprises.

Externalities lead to a discrepancy between private and public expenditures (social expenditures are equal to the sum of private and external ones, that is, non-pollutants and third parties), private expenditures are less than public expenditures. In order to reduce the overproduction of goods and services with negative external effects and to fill the underproduction of goods and services with positive external effects, that is, to transform external effects into internal, internalization of external effects is necessary. The essence of Pigu's corrective taxes is not to punish those who create negative externalities, not to compensate the external entity and even not to raise funds in the state budget, but to restore market equilibrium at a level that ensures optimum society, production and consumption of goods In developed countries, the state and society are trying to minimize balances. The basis was laid on the principle of organization of production,

which means the use of raw materials and energy in an enclosed cycle. An enclosed cycle means a chain: primary raw materials – production – consumption – secondary raw materials [16].

In developing countries to which Ukraine belongs, development is most often due to the use of natural resources and the slow introduction of intensive technologies.

While taking into account environmental influence, it is compulsory to analyze its intensity, which depends on the exposure time, the volume of the influence factor and its toxicity [16]. When analyzing the impact of waste on the ecosystem using the example of garbage that has been accumulated and must be transported to the landfill, we take into account the amount of waste that arrives at the landfill or the amount of toxic substances released into the ecosystem:

$$V = \sum_{i=1}^{n} w_i(k_{ij} + l_m), \quad (3)$$

where V is the volume of the environmental impact factor (for example, waste), w_i – is the daily average (monthly) toxic substance release rate (waste generation rate), k_{ij} – is the time frame between deliveries from the sources of debris generation to the landfill, l_m – is the time required for transportation of garbage from the place of generation to the landfill, n – is the number of waste generation sites [17].

For example, I can observe such negative impacts that can be measured and quantified: the volume of toxic filtrate that is released into the soil over a period of time, the amount of toxic substances (on indicators) that are released into the air.

The total effect can be calculated by the formula:

$$F = (K_I + V + K_T)t, \quad (4)$$

where K_I – is the intensity coefficient of the impact factor, V – is the volume of the influence factor, K_T – is the toxicity coefficient, t – is the exposure time at the landfill.

So, with the income of a model company that grows sunflower seeds and sells them fried in packaging materials – 800 thousand UAH (8 tons – 4 ha), the profit excluding the cost of manufacturing the product, selling, transporting and paying taxes is about 150 thousand UAH. Although, taking into account the expenses of disposal of packaging materials (about 5,000 UAH at the price of waste disposal in Ukraine) and restoration of soil conditions to zero (with a yield of 2 t/ha, about 60 kg of nitrogen, 30 kg of phosphorus and 50 kg of potassium are removed from the soil and other elements, while there is poisoning of the soil with preparations for deworming and weeds. The average price of restoration of the investigated field is 50 thousand UAH), then the profit will be about 96 thousand UAH.

From the results of the observation it follows that the average decrease in profit for a sample of ten enterprises in the field of agricultural production in the Kiev region is about 50 percent of total profit, which affects the profitability of the enterprise and the payback period. If each entrepreneur takes into account the negative impact on the ecosystem and minimizes it, along with a decrease in profits, gradual economic growth will begin in connection with the introduction of new technologies and the improvement of living standards. To do this, it is worth changing the legislation, making it more stringent, increasing fines and control.

With an increase of negative environmental influence factors, losses are added up and reduce the total profit of enterprises.

4 Discussion

The necessity for an integrated manner of the environmental burden at all levels of society should be reflected in taxes and fixed at the legislative level. This would help to reduce the negative influence on the environment and would be controlled by the state, the leadership of which should be interested in increasing the state budget and improving the life of the population [18].

When analyzing current expenditures and investments in environmental protection according to the State Statistics Committee of Ukraine [12], for the first sight, their volume grows, however, while analyzing the increase in the rate of negative influence, its accumulation effect and inflation processes, it becomes clear that the situation is getting worse every year (Fig. 3).

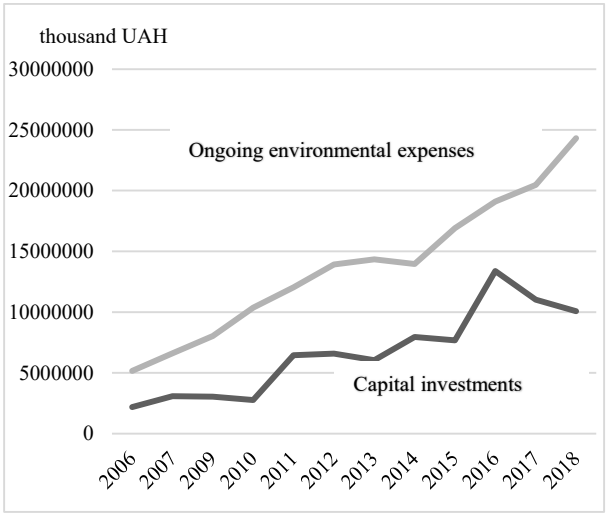

Fig. 3. Current Expenses and Capital Investments for Environmental Protection in Actual Prices on the Time Interval, thousand UAH [12]

Figure 3 shows a slight increase in expenditures and investments in environmental protection, however, in US dollar equivalent, the trend line has a smaller inclined angle and a lower coefficient of determination (which can be seen if you build a trend line, taking into account the inflation level in Fig. 4, in the interval from 2006 to 2018), which indicates the instability of the situation (greater deviation) and the slow growth of rate of cash proceeds , which is not able to significantly

affect the negative consequences of anthropogenic influence.

Taking into account the effect of accumulation and corruption in Ukraine, the problem remains open and is constantly becoming more acute, affecting the quality of life of the population [19].

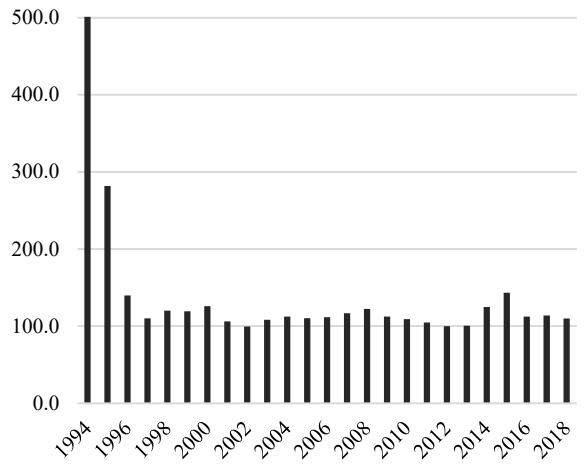

Fig. 4. The Inflation Rate in Ukraine on the Time Interval, 1992-2018, % (till December of the previous year) [12]

Fig. 4 shows that the consumer price index is less than 100% only in 2002 and 2012, it is more than 100% in other years of the researched interval, which indicates constant inflation with an average value of 37%, which indicates a high rate of depreciation of the national currency, a decrease in the consumer population basket and the real costs of environmental measures [20]. The economic instability causes the outflow of investments and reduces the likelihood of investing in resource-saving technologies, while the structure of consumption balances changes towards fractions that have a long decomposition period, and the amount of packaging materials increases and becomes a threat to the existence of the natural environment [21].

The use of Leontyev-Ford models in calculating the resulting indicators is optimal, because the target function is not only income growth, but also a negative influence on the environment exposed to anthropogenic impact.

5 Conclusions

According to the growth of indicators of economic development (standards of living of population) of the country, the volumes of household and industrial wastes and industrial production are growing significantly. The natural power of the external environment is already becoming insufficient for the timely disposal of an increasing amount of household waste and negative externalities. The first countries to face with this problem were high-income countries and significant population densities. These are, first of all, highly developed countries of Western Europe.

The assessment methodology of economic indicators requires taking into account environmental impacts, which would better reflect the current state of both selected indicators and the general economic situation in the country. Minimization of the residual production while maximizing profits is proposed to be the targeted function which in turn will affect the performance and the overall level of the country's GDP.

But the result of evaluating the effectiveness of investments in solving the problems of environmental pollution in China showed that investments in the control and combating of water pollution and industrial waste pollution are not given due attention, i.e. public investment in these areas to combat pollution is ineffective [22].

The functioning of the Zero waste concept is considered to be the basis for further development which minimizes the impact of negative externalities.

The situation with the negative impact of human activities on the environment in Ukraine becomes more acute every year due to the accumulation of negative effects and a decrease or deterioration in the quality of natural resources. Environmental allocations are not enough to solve the problem, and corruption and the unwillingness of the government and entrepreneurs to change the situation still slows down the speed of implementation of new technologies and changes for the better.

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Accounting, analysis and environmental audit as an imperative of the development of green economy in the state's economic security system

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Abstract. The necessity of using accounting and auditing system is substantiated in the article, its main advantages are also defined. A model of accounting and audit support has been developed in the article, suitable for usage by forestry enterprises. In the system of rational forest management, accounting and auditing support of its management is of paramount importance, because it allows to monitor, document and verify for reliability all parties of financial and economic activities of forest users. In developing a system of accounting and audit of rational forest management, we are based on the fundamental categories of the classical scientific process, so its main elements are the object, subject, methods and subjects of research in the context of the relationship between the two components – accounting (by types) and economic and environmental audit of forest resources. Conducting an environmental audit in the forestry sector is complicated by the complexity of the audit object and the contradictory and multi-level relationships between its main elements. Internal audit is one of the few available and at the same time undervalued resources, the proper use of which can improve the efficiency of the enterprise and contribute to the orderliness of the management of economic processes.

1 Introduction

Information support of economic phenomena and processes today is a prerequisite for the development of effective management strategy, which is the basis for improving the efficiency of all economic activities without exception. In the context of growing demands for economic information, it is important to highlight and clearly differentiate the individual components of the information environment. For forestry, this issue is actualized due to the peculiarities of forest management, the length of the production cycle, which complicates the objective reflection of business operations in the formation and use of forest assets.

The aim of the study is based on providing theoretical approaches to the system of accounting and audit of rational forest management, which will improve the efficiency of forest management through the use of a set of institutional mechanisms of economic and environmental assessment, reflection and control of the use of forest biological assets, taking into account the dynamic balance of environmental, economic and economic balance, environment and society.

2 Results and discussion

The basis of rational forest management in the overall strategy of sustainable socio-economic and ecological development of the country focused on long-term perspective is the balancing of anthropogenic impact on forest biogeocenosis and ensuring parity between the growing needs of forest users and natural opportunities of the forest.

Global negative trends of recent decades are disturbance of the breed composition of forests, change of their age structure, thinning and weakening of biological stability of forest stands. Particularly acute and urgent are the problems of forests in Ukraine, where the forest cover is one of the lowest in Europe (Table 1).

Table 1. Forests in Europe.

Country	The total area of the territory of the country, thousand hectares	Area of forested land, thousand ha	Forests, %
Ukraine	60370	9675	16,0
Sweden	45218	27264	60,3
Finland	33814	21883	64,7
France	54919	15156	27,6
Spain	50596	13509	26,7
Germany	35702	10740	30,1
Italy	30132	9857	32,7
Poland	31268	8942	28,6
Norway	32376	8710	26,9
Belarus	20767	7850	37,8

To bring the forest cover to the optimum level (about 20%), it is necessary to accelerate the afforestation of all

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log cabins and forest areas not suitable for agriculture, steep slopes, level girder systems and deflated sands. Such measures will expand the country's forestry and environmental potential and conserve biodiversity. The main criteria for the cost-effectiveness of afforestation will be the reduction of erosion losses and the production of additional crop production [1]. It is worth noting that in Ukraine, as an agrarian state, there are no large reserves of areas that can be afforested, so it is not always possible to bring the actual forest cover level to the optimum due to objective circumstances.

The priority task of forestry enterprises is the restoration of forests (the process of formation of a new generation of forest under the tent of stands, log cabins, combustions and other areas where it has previously grown), which is carried out to achieve optimal forest cover, increase water protection, soil protection , other beneficial properties of the forest, improving the quality of plantations.

In the context of a critical level of anthropogenic load on natural resources, there is an objective need to rethink approaches to the management of natural assets in general and forest resources in particular, which should be based on the principles of sustainability, non-exhaustion and rationality. Green space is a sign of civilization, the cheapest and most effective biological means of environmental purification. Therefore, in view of the specific nature of the problem of global nature, it is important to summarize the concepts of "sustainable management", "sustainable forest management" and "rational forest management" to ensure uniformity in making effective decisions at all levels of management.

In the system of rational forest management, accounting and auditing support of its management is of paramount importance, because it allows to monitor, document and verify for reliability all parties of financial and economic activities of forest users (Fig. 1). Let us analyze each element of the accounting and auditing aspect of sustainable forest management.

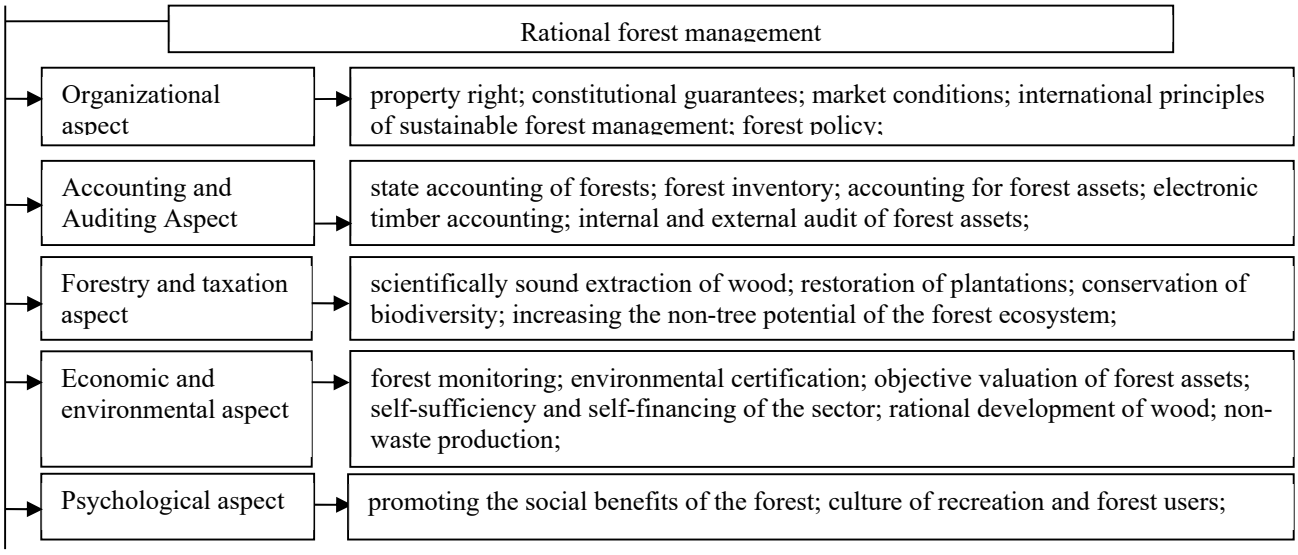

Fig. 1. Forest management system.

Without a developed system of accounting and synthesis of information about the past, present and future events of the economic life of the enterprise it is impossible to make sound and prudent management decisions, which can lead to the risk of loss of control over financial and economic activities. Therefore, in order to increase the efficiency of activities, it is necessary to create an optimal organizational structure of management [2]. Accounting, as one of the tools to implement a management function, must be conducted in accordance with certain rules that maximize the effectiveness of management decisions made on their basis. The effect of proper accounting is reflected in timely preparation and submission of financial statements, preparation of other management information.

In our opinion, the contribution of audit to improving the reliability of accounting and analytical information is so significant that it is appropriate to distinguish a separate concept of "accounting and auditing" management of economic processes and phenomena. We believe that this definition is broader in nature because it covers a range of issues pertaining to the ongoing control over the formation and evaluation of accounting information. Thus, summarizing all of the above, we consider it appropriate to define accounting and auditing as a system of tools for collecting, assessing, processing, summarizing and accurately displaying accounting and analytical information for management purposes.

The current realities of forest management in the Ukrainian economy indicate that there is no clear strategy for accounting and auditing of forest management.

Accounting for forestry products does not ensure the exercise of control and management function, and the inconsistency of some aspects of it with international standards lead to obvious financial abuse in the industry. In view of increasing requirements for operational management of the assets of an enterprise, it is important to expand the information base, which will increase the efficiency and objectivity of tactical plans. In this regard, the rational forest management accounting and auditing system is intended to optimize and improve decision-

making on sustainable forest management. It allows you to:

- generate complete and reliable information about forest users' economic activities and their property status;
- prevent negative results and reduce economic risks and identify internal reserves for ensuring the financial stability of the enterprise;
- control the availability, movement of property, manage the rational and purposeful use of material, labor and financial resources;
- make a scientifically sound system of indicators characterizing the results of the activity of the enterprise, its separate divisions and services;
- comply with state discipline and lawfulness when dealing with economic issues.

Taking into account the specific features of forestry, the accounting and audit system also promotes:

- reliable assessment of plantation groups by age and breed composition, to further reflect them in the composition of non-current assets of forest users;
- regulation of expenses incurred by the enterprise during the turnover of the logs, with subsequent inclusion in the cost of finished products to calculate the objective cost of production;
- avoiding unacceptable losses of wood in the chain "ex-timber – ex-upper warehouse – ex-lower warehouse – consumer";
- control of the volume of forest plantations allocated for sanitary solid and selective felling;
- prompt reflection of all qualitative and quantitative changes that have occurred in the composition of forest assets as a result of realization of processes of forest users' economic activity.

In developing a system of accounting and audit of rational forest management, we are based on the fundamental categories of the classical scientific process, so its main elements are the object, subject, methods and subjects of research in the context of the relationship between the two components – accounting (by types) and economic and environmental audit (by type) of forest resources (Fig. 2).

As can be seen from the diagram, together with the accounting of forest resources, the simultaneous use of the main tools of auditing control of forest assets is envisaged. Given the exceptional importance of forest ecosystems in quaternary processes, forest audits should be conducted not based on the traditional economic criterion of efficiency but on the criterion of economic, environmental and social efficiency of forestry. That is why we propose to introduce into scientific circulation the concept of economic and environmental audit. A distinctive feature of the economic and environmental audit of the forest sector is the establishment of environmental validity and legality of forestry and reforestation.

In the context of material production, accompanied by increasing pressure on the environment and excessive depletion of natural resources, it is important to provide the public, state institutions, economic entities with reliable, timely and objective information on the state of natural ecosystems, measures taken to green the production processes and opportunities to prevent the spread of corruption tendencies in economic activities of environmental users.

Forest management features make this issue more relevant in the absence of a transparent and impartial systematic control over operations that affect the environmental status of forest biogeocenosis. This task is facilitated by the implementation of forestry practices of external and internal economic and environmental audits, which, as a means of identifying doubtful financial and economic transactions that can serve as a source of shadow income and unjustified environmental risks, occupy an important place in the economy and the system of economics farms. In addition to audits, auditing is also an effective way of controlling the targeted use of budget funds in forestry enterprises. In the separate concept of internal economic and environmental audit of forestry by scientists has not yet been identified, so we consider it necessary to submit our own interpretation of this definition, which defines internal economic and environmental audit as a component of the internal control system, which is an independent, comprehensive, documented assessment of the activities of forest users subject to compliance with the requirements of the applicable economic and environmental law in order to provide practical recommendations for improving the effectiveness of management decisions to prevent Nude risks of error, fraud, waste, etc., and promotes rational forestry.

Conducting an environmental audit in the forestry sector is complicated by the complexity of the audit object and the contradictory and multi-level relationships between its main elements. In addition, the downward trend in effective demand for audit services requires forest sector enterprises to organize in-house control of forest biological assets through the introduction of internal economic and environmental audits as an effective tool in improving the efficiency of management of forest management.

Internal audit is one of the few available and at the same time undervalued resources, the proper use of which can improve the efficiency of the enterprise and contribute to the orderliness of the management of economic processes. The main objective of an environmental audit is to optimize the financial and economic activity of the enterprise not by detecting irregularities and mistakes for further organizing and punishing the perpetrators, but by finding and assessing risks, weaknesses in the work of the structural unit or enterprise and providing practical recommendations for improving the efficiency of adoption management decisions. Given that internal audit provides information on all aspects of the enterprise's activities and tools for generalizing and analyzing data, interacting with it enhances the effectiveness of the decisions made. It provides expert science-based assessment of business operations and processes.

The peculiarity of internal economic and environmental audit in forestry enterprises (as opposed to audits or external audit) is its perspective orientation, that is, the design and analysis of future events that may adversely affect the environmental condition of forest assets and prevent the threat of loss control and loss

control. ecological validity of carrying out separate production and economic processes in state forestry.

The prerequisite for the use of internal economic and environmental audit in forestry enterprises is the development of a legal framework, control parameters, standards, etc. in coordination and compliance with the geographical (natural and climatic) features of forestry.

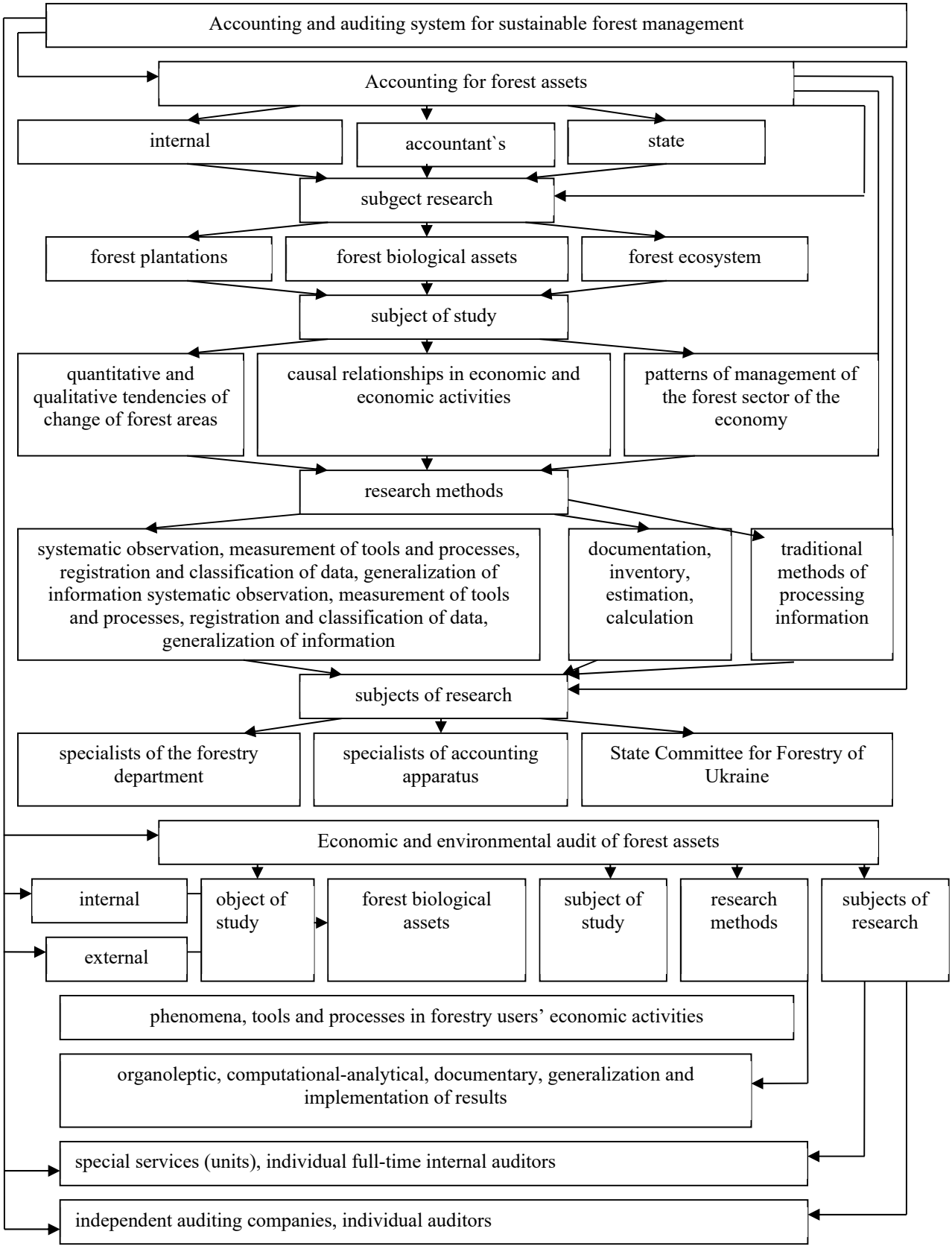

Fig. 2. The system of accounting and audit support of rational forest management.

The organization and conduct of internal economic and environmental audits must comply with certain principles, among which the following are the main ones:

- the obligation to take into account the requirements of environmental safety and sustainable development of the territory;
- accounting and assessment of natural and socio-economic features of the territory, current and prospective state of the environment;
- the accuracy and completeness of the information used for the audit;
- scientific validity, objectivity and openness of audit results.

Internal audit aims at internal control over the organization and functioning of accounting systems - not only accounting, management, operational, but also environmental, which is based on the systematic use of economic and environmental information on the status, formation and use of audit objects in accordance with to the requirements of environmental legislation and conceptual principles of sustainable forest management. Control over the organization of the accounting system is the implementation of part of the management functions of the management of the company, so the performers of internal economic and environmental audit should be impartial and objective in their analytical actions and provide a complete and permanent assessment of financial and economic processes from the standpoint of economic, environmental and social feasibility.

Internal economic and environmental audit in forestry performs a number of tasks, the main of which are:

a) collecting reliable information on environmental aspects of forestry production activities;

b) establishing the compliance of forest ecosystems with the requirements of the legislation on environmental protection and other criteria;

c) evaluation of the results of the activities of forest users in the context of environmental impact;

d) assessment of the effectiveness, timeliness, completeness and validity of the measures taken to minimize the negative impact on the forest ecosystem and the environment;

e) preparation of recommendations on optimization of the use of forest resources and prevention of environmental risks in the activities of forestry enterprises.

Internal audit, as a management tool for forest management, should be considered on a systematic approach. Based on the systematic approach to management, we have developed a procedure for implementing accounting and control functions of management (through internal audit), in which all stages, depending on the performed operations, are divided into separate blocks: planning, organization, execution, control (Fig. 3).

The general model of internal economic and ecological audit of the enterprises of the forestry sector looks like this (Fig. 4).

In the audit process, the priority is to verify:

- compliance of primary forest accounting data with the state forest inventory;
- the availability of legal support for permanent use of forests, which is certified by a state act on the right of permanent use of land;
- compliance of the actual sizes of the plots allocated for special use with the standards of the calculated logging;
- the proportionality of the volume of actual removal of timber with the norms (limits) of harvesting timber from logging;
- observance of the proportions recommended by the state forestry organizations regarding the yield of timber by the breed composition of plantations (coniferous, softwood, hardwood) and especially valuable breeds;
- completeness of development of logging fund in accordance with assortment tables;
- the validity of the logging waste and primary wood processing and the completeness of their use in economic activity;
- the lawfulness of permits for the special use of forest resources in the allocated forest area (logging tickets, warrants, forest tickets);
- compliance of the actual volumes of timber extraction with the volumes specified in the permits;
- the size of defects (at certification of places of harvesting) in development of the logging fund;
- compliance with the timing of collection of forest resources.

Systematic operations are also subject to operations with recovered wood. In this context, it is important to check:

• conformity of the quantitative and qualitative (breed and assortment) composition of the wood indicated in logging tickets to the actual sizes on logs, upper and lower storage depots;

• the reliability of the cost estimate of the forest products received and the validity of its initial posting in the accounting of state forestry;

• comparability of fuel standards and actual volumes of timber released to employees;

• volumes of timber (including export deliveries) broken down by breed and assortment composition during the reporting period (quantitative and cost indicators are checked for detection of discrepancies between the data of primary documents and actual residues of timber production in warehouses);

• the accuracy of the costs incurred by the enterprise in harvesting the timber;

• the lawfulness of the distribution and attribution of costs for the production cost of sales;

• accounting for operations related to the procurement and sale of secondary forest materials and by-products of forestry (including specially created for this plantation), which are carried out for the needs of production and commercial activities in the order of special use and are carried out for payment on the basis of the forest ticket within the allotted areas of the forest fund;

• objectivity in accounting for the costs of forestry services.

Summarizing the above, it should be noted that the implementation of internal economic and environmental audit of forestry enterprises is a labor-intensive process, the results of which can significantly improve the effectiveness of the decisions taken on the management of

rational forest management and prevent unjustified economic and environmental risks in the future. Therefore, the search for opportunities and the development of practical recommendations for improving environmental safety, biodiversity conservation and sustainable forest management should be based on a systematic study:

- ways of improving industrial environmental control;
- possible steps to improve the forest ecosystem protection management system;
- the most effective available technologies for accounting of forest assets, advanced rational development of forest resources and mechanisms for timely and complete reproduction of forest plantations.

This paved the way for new challenges – to evaluate, through internal audit, the state of forestry and the main opportunities for improving its economic and environmental performance.

The optimal and efficient use of waste as a valuable raw material for processing minimizes the loss of forest products and increases the economic and environmental impact of sustainable forest management. The main possibilities of waste recycling, to increase the economic effect are: production of technological chips, tare boards; manufacture of building structures (eg., arbolite, xylolite, parquetite); production of structural fiber materials (eg., fibrex); bio conservation; production of fuel briquettes (briquettes from wood waste and bark do not actually contain sulfur, so in the products of their combustion there is no sulfur gas, and the content of carbon monoxide is minimal); production of fuel wood pellets.

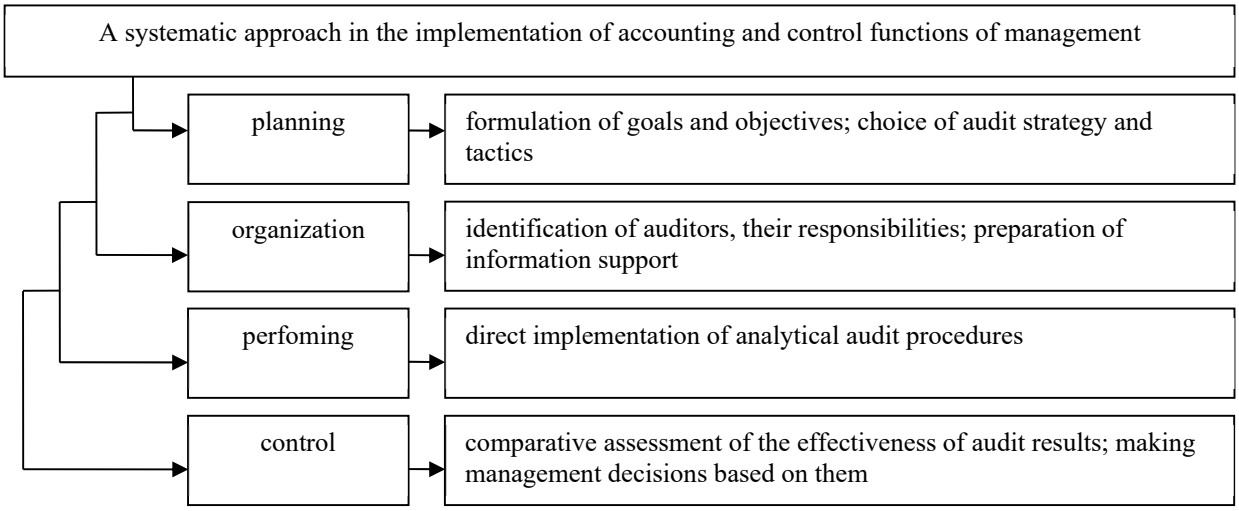

Fig. 3. The algorithm of implementation of accounting and control function of management.

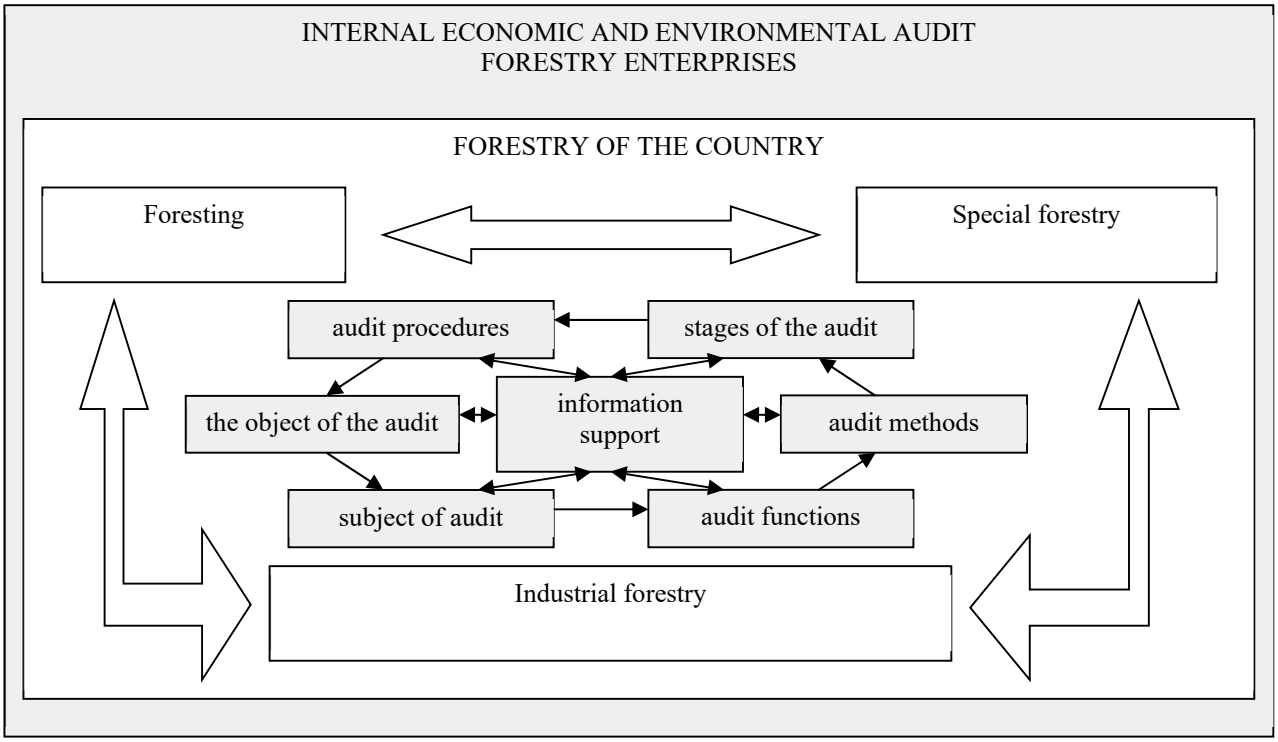

Fig. 4. Model of internal economic and environmental audit of forestry enterprises.

To increase environmental efficiency, the experience of grinding forest waste to a small fraction, followed by scattering over the area of the forest area, is positive, which allows:

- to provide optimal conditions for seed germination (and therefore promotes the natural restoration of forest plantations);
- to control the phytosanitary state of forests and prevent the occurrence of pests (due to the balance of the mineral nutrition of plantations).

3 Conclusions

Todays World green economy trend is not only about nature management in real day to day life, it is also about information support and assurance of such managmet, that is based on nature managing accounting procedures. It assures base for green economy development planning and control of it`s performing throught the permanent analisis of changes and its impact on future green economy parametrs. Green economy needs management approachs of permanent optimization that is based on effective and trustworthy data provided by cvalifide persone – auditor. Green economy audit, that is based on accounting and analitic data provides directions of srtategyc effective segment developmet to overcome World ecological problems. Novedays there is only one worldknown instrument that provides reall independent analisis and recommendations of different process optimization – audit. Green economy also is under it`s sphere of influence and neeed to be considered as “must”.

Thus, balancing the cost structure, strengthening the internal control over the processes of restoration and use of forest biological assets, will contribute to the deepening of rational forest exploitation, based on environmentally sound and cost-effective principles. The practical value of economic and environmental audit under these conditions is to improve the mechanism of making effective management decisions to increase the resource potential of forestry, as a necessary prerequisite for ensuring sustainable forest management.

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Modelling and forecasting of the region's environmental indicators

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Abstract. The environmental situation in the Khmelnytskyi oblast has been analyzed, models and forecasts of indicators have been developed by methods of extrapolation, regression analysis and trend models, and the quality of forecasting has been estimated. Namely, the models of influence of selected factors on the environmental situation in the Khmelnytskyi oblast have been developed. One- and multifactorial regression models have been constructed, conclusions about the degree of influence of factors have been made. Trend models of indicators of the ecological situation in the region have been constructed. Estimates of pollutant emissions, indicators of the creation and disposal of hazardous waste have been developed using different forecasting methods. These calculations can be used to carry out activities aimed at protecting the environment.

As a result of human economic activity in the natural environment, non-typical substances are accumulated, with solid wastes (garbage) and chemical compounds that lead to environmental pollution among which. The main sources of pollution are airborne industrial enterprises and transport [1]. The formation of ecological consciousness and ecological culture should stand in the way of human attitude towards nature; this includes rational use of nature resources, severe control over emissions and exploitation of natural resources. Targeted integrated environmental programs are required to address environmental issues related to the proper protection of atmospheric air, water and land, with the utilization and disposal of waste [2].

Therefore, the study of environmental problems, modeling of the impact of economic costs on the disposal of hazardous wastes and the prediction of pollution indicators of the territory is relevant.

The purpose of this study is to provide a theoretical justification and practical implementation of existing approaches to the study, modeling and forecasting of environmental performance indicators by methods of economic and mathematical modeling. The current environmental situation on the territory of Ukraine can be generally described as tense. When studying the situation in the environment, the impact on it of different types of pollutants must be taken into account [3]. And, as a rule, they not only worsen the environment, but also adversely affect certain environmental systems and organs of the human body, which can lead to serious diseases (Table 1).

Sources of pollutants are varied, as well as numerous waste types and characteristics of their effects on the components of the biosphere (Table 2).

When determining the influence of harmful substances on a person, plant and animal organisms, the degree of pollution of the environment, the norms of quality are used [6], expressed in the maximum permissible concentrations (MPC) of harmful substances, the maximum permissible levels (MPL), the maximum permissible emissions (MPE), of the pollutant in different environments (Table 3).

Table 1. Impact of some pollutants on human health [4].

Substance	Sources	Impacts on Health
Chemicals of different classes	Use of pesticides	carcinogenic, mutagenic
Surfactants	Use of detergents	allergies, dermatitis
Petrochemicals, organic solvents	Petroleum refining and other industrial processes	headache, loss of coordination, carcinogenic impact, bone marrow lesions
Vinyl chlorides	Production of plastics, synthetic films	carcinogenic, mutagenic
Dioxins	Waste processing, pharmacological productions	carcinogenic, mutagenic dermatogenic
Heavy metals: Pb	Use of paints, motor fuels	neutroxidation, mutagenic
Hg	Use of electronics, brake and hydraulic fluids, fluorescent lamps	carcinogenic, mutagenic dermatogenic
Cd	Production of batteries, mineral fertilizers	carcinogenic, mutagenic

World experience shows that with the aggravation of environmental problems and the deterioration of the environment, the centralized administrative systems of environmental management have been created and

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strengthened in all developed market economies [7]. Today, the EU countries are combating incinerators that have outdated technologies and pollute the environment and have toxic residues. Instead, scientists propose to innovate [8]. The structure of waste recycling in different countries of the world is presented in Table 4.

Table 2. Sources of environmental emissions [5].

Industry	Type of emissions	Harm
Coal, metal, paper	Emissions containing sand particles, rocks and other mechanical impurities	May disrupt natural ecosystems, sanitation, muddy bottoms and shores
Mechanical engineering plants, chemical industry enterprises	Emissions from neutralization and sewage	The environment is polluted by heavy metal salts, cyanides, acids, toxic organic and inorganic compounds
Mining, coal mining, tanneries	Contamination containing micro- and macronutrients	Contamination of the environment with excessive amounts of micro- and macronutrients, in some cases pathogens
Alcohol, sugar, starches and other enterprises	Contamination containing organic compounds of vegetable and animal origin	Environmental contamination by easily decaying organic compounds can cause infectious diseases

Table 3. Air pollution assessment criteria [6].

Contamination level	Danger rate	Percentage of excess of MPLs
Acceptable	Safe	0
Unacceptable	Low Dangerous	> 0…4
Unacceptable	Moderately dangerous	> 4…10
Unacceptable	Dangerous	> 10…25
Unacceptable	Extremely Dangerous	> 25

Table 4. Waste recycling in different countries (data as of 2015).

Countries	Total number of waste, mln tons	Composting		Burning, %	Burial, %
		%	mln t		
Denmark	15,54	69	10,72	23	7
Belgium	5,56	67	3,726	30	2
Germany	48,85	63	30,77	33	1
Ireland	2,58	42	1,084	43	57
Italy	32,89	39	12,82	15	46
Norway	9,36	33	3,09	30	16
Poland	4,78	18	0,860	1	73
Portugal	5,47	20	1,093	19	16
Spain	31,19	39	12,16	7	54
Sweden	4,33	48	2,08	51	1

Regarding the situation in the Khmelnytskyi oblast, the studies have shown that during the last twenty years of observations there has been a general reduction of pollutant emissions into the atmosphere. However, the problem of recycling, storage and processing of industrial toxic and household waste is becoming more acute for the region. The total amount of waste generated and accumulated in the storage facilities of enterprises has increased over the last year.

The problem of increasing the volume of solid household waste is also compounded by the large volume of solid municipal waste that is generated by economic activity (Figure 1).

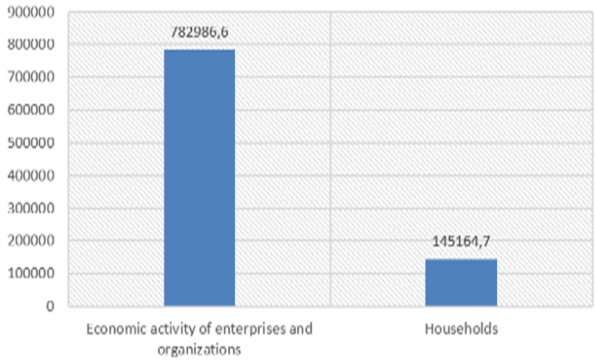

Fig. 1. Waste generation by type of economic activity and households in 2018 in the Khmelnytskiy regional [9].

The best disposal of waste should be the use of waste as secondary material or energy resources. Figure 2 shows the waste management in 2018 in Khmelnytskyi.

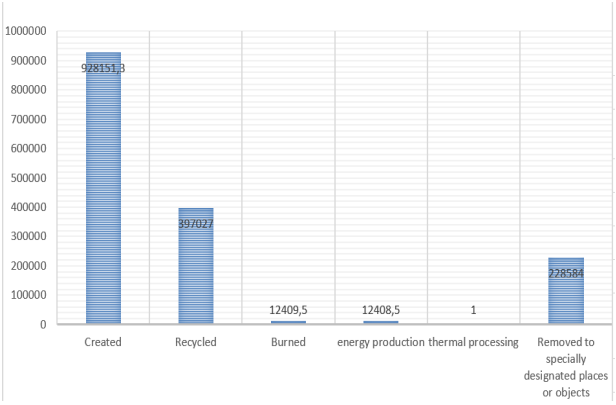

Fig. 2. Generation and management of I-IV waste classes by category of materials in 2018.

Unfortunately, the volume of discharged contaminated wastewater into water bodies and the volume of pollutants have increased, but the designated areas and waste disposal facilities are increasing [10]. At the same time, attracting investment for environmental improvements requires identifying the sources of these investments, which is an important task. Therefore, environmental spending has increased in size and scope. The total amount of expenditures for environmental protection increased in 3.1 times during this period.

In the current conditions, the process of environmental research should be taken to a new level, in particular, it is necessary to develop new approaches to the application of econometric models and methods for forecasting indicators at the regional level. The following information was used to model the environmental situation of the Khmelnytskyi oblast (Table 5).

Table 5. Baseline data for modeling of one-factor models [9].

Years	Emissions of pollutants, thousand tons	Hazardous wastes generated, t	Disposal of hazardous waste, t	Capital investments for environmental protection, thousand UAH
	Y_1	Y_2	Y_3	x
2006	57,9	1212,2	308	13547
2007	87,5	1750,9	223,5	17627,1
2008	92,1	1719,5	269,3	11584,2
2009	81,5	1018,1	141,9	6744,8
2010	83,8	1435346,7	260096	4358,1
2011	83,5	1596823,7	288750,1	3853,1
2012	79,7	1471062,1	526377,4	13915,6
2013	80,7	1111642,5	492198,5	10164,6
2014	79,2	1266163,8	305155,4	6816,9
2015	75,5	960913,9	345947,4	19254,1
2016	21,7	1299637,3	450101,4	36718,5
2017	21,1	928151,3	397027	35863,5

The resulting regression models are as follows:

$$Y_1 = 99.32628 - 0.00193x \quad (1)$$

$$Y_2 = 829707.4 + 0.65921x \quad (2)$$

$$Y_3 = 166195.6 + 5.942164x \quad (3)$$

In modeling, only the obtained model (1) which is the impact of the amount of capital investment on environmental protection, showed a high correlation between the factor and the result.

Therefore, the models were obtained, of which only one is adequate, which confirms the relationship between capital investment and the pollutant emission rate. As the sign near the factor is negative, its increasing leads to a decrease in the resultant indicator, that is, the increase in capital investment for environmental protection reduces the amount of pollutants. Figure 3 presents the actual and calculated indicators by model (1).

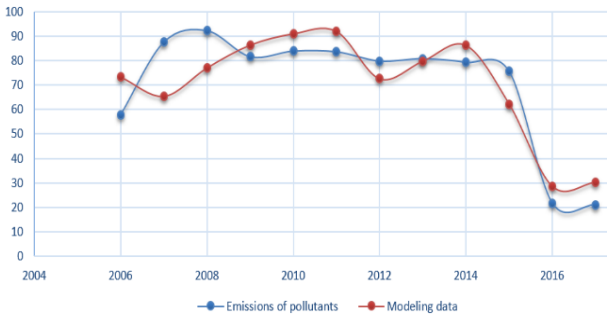

Fig. 3. Dynamics of actual and calculated indicators according to the model of the studied indicator "pollutant emissions".

The following multifactor models were built. As the indicators, the dynamics of the pollutant emissions were also taken, the hazardous waste generated and disposed. As for the factors, the economic indicators reflecting the costs of environmental protection, were taken (Figure 4).

The following models are based on performance indicators: Y_1 – Emissions of pollutants, thousand tons, Y_2 – Hazardous wastes, Y_3 – Disposal of hazardous waste, t. The influencing factors are: x_1 – atmospheric protection and climate change; x_2 – sewage treatment; x_3 – waste management; x_4 – protection and rehabilitation of soil, groundwater and surface water; x_5 – conservation of biodiversity and habitat; x_6 – other areas of environmental activity [8].

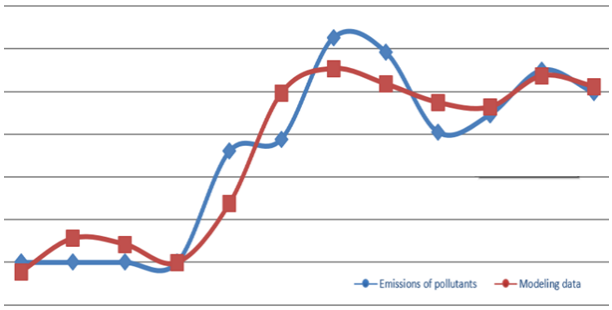

Fig. 4. Dynamics of actual data of the studied indicator "Recycled" and calculated according to the multifactor model.

In the case of multiple correlation, the so-called multicollinearity may be present which is correlation dependence between factors, so it was checked and it was concluded that there was no significant correlation between the selected factors, and therefore all factors could be used to construct the models.

The analysis of the regression statistics has led to the conclusion that all three multifactor models have high correlation and determination coefficients, i.e. they confirm a strong correlation between the selected factors and the performance indicators. The adequacy of the constructed models can also be estimated from the results of the Fisher test, which allows to estimate the significance of linear regression models: in all three multifactor models, this criterion is larger than the table value (2.99), which indicates the approximation of empirical data to the performance indicators, i.e modeling.

The obtained multivariate regression models are as follows:

$$Y_1 = 89{,}36329 + 0{,}002334x_1 + 0{,}002022x_2 - 0{,}005x_3 - 0{,}00693x_4 - 0{,}00559x_5 - 0{,}00086x_6 \quad (4)$$

$$Y_2 = 1883120 - 38{,}1355x_1 - 15{,}8833x_2 + 56{,}38903x_3 - 271{,}267x_4 - 65{,}8728x_5 - 28{,}0498x_6 \quad (5)$$

$$Y_3 = 392046{,}3 - 6{,}37886x_1 - 10{,}1655x_2 + 19{,}03229x_3 - 55{,}4992x_4 + 70{,}66399x_5 - 3{,}893x_6 \quad (6)$$

With regard to the first performance indicator (pollutant emissions), it has the greatest impact on the costs of return water treatment and air protection, and the costs of soil protection and rehabilitation reduce emissions. The formation of hazardous waste factor affecting spending on biodiversity conservation and habitat. The third model (hazardous waste disposal) has the greatest impact on the cost of "waste management and conservation of diversity". Increasing the cost of these factors will increase waste disposal.

Figure 4 presents the actual and predicted data from one of the models obtained.

The obtained dependence equations can be used for predictive calculations. Substituting new values into these equations allows us to obtain the predicted value of a performance indicator.

We have increased all environmental costs by 20% and, according to the regression model, we have projected a reduction in pollutant emissions up to 16.3 thousand tons (Table 6), which is 4.8 thousand tons less than in the last year.

Table 6. Forecasting the indicators of regression multivariate models.

	Forecast	Forecasted indicators					
		x_1	x_2	x_3	x_4	x_5	x_6
Y_1	20,20624	5353,44	77883,9	26393,6	2114,52	2631,6	13114,5
Y_2	726845						
Y_3	434550,1						

This study points to the need to focus on factors such as environmental costs. The most efficient use of financial and economic resources will allow to reduce the emissions of pollutants.

The next step in the study is the forecast of selected indicators by the methods of predictive extrapolation, which are the most accessible for technical implementation.

When forecasting by extrapolation methods we proceed from the inertia of phenomena (processes) that are studied and predicted [11].

To assess the quality of the forecast results, we will use the actual values of the exogenous variables, that is, the "ex post" method [12]. Table 7 presents the results of the projection of the environmental indicator for the environment "Emissions of pollutants" for 2018 and its comparison with the actual indicator for the same year.

Table 7. Forecasting of the "Pollutant emissions" indicator and checking the quality of the forecast.

The actual value	Forecasting	Absolute deviation	Relative deviation, %	Forecasting methods
21,1	7,20	-13,9	-65,8	Average absolute gain
	15,67	-5,4249	-25,7	Average annual growth rate
	10,36	-10,742	-50,9	Method of fluctuating average

As can be seen from the table, all the forecasting methods did not perform very well. The average annual growth rate was the best among simple forecasting methods, it showed the smallest deviation from the actual data (25.7%), the worst in this case was the average absolute growth method (65.9% deviation).

Table 8 and 9 present the results of the forecasting of the "Formation" and "Disposal of Hazardous Waste" values.

As can be seen from Table 8, the formation of hazardous waste tends to increase. But all the prediction methods were inaccurate in this case, since they all have a large error of more than 10%.

Table 8. Hazardous waste generation forecasting and quality assurance.

The actual value	Forecasting	Absolute deviation	Relative deviation, %	Forecasting methods
928151,3	1256781,1	328629,8	35,4	Average absolute gain
	1259998,3	331847	35,7	Average annual growth rate
	1336946,1	408794,8	44,1	Method of fluctuating average

Table 9. Hazardous waste utilization and quality assurance of the forecast.

The actual value	Forecasting	Absolute deviation	Relative deviation, %	Forecasting methods
397027	431032,4	34005,4	8,56	Average absolute gain
	432826,3	35799,3	8,6	Average annual growth rate
	463887,8	66860,8	16,8	Method of fluctuating average

As it can be seen from Table 9, the indicator for the disposal of harmful emissions tends to increase. Two forecasting methods showed an error of deviation from the actual data of less than 10%, and the current average method of more than 10%, i.e. it is not recommended to be used for forecasting.

The reason for the big error is the instability of the dynamic data series. The reason for the deviation from the actual data may be the disadvantages of these methods, namely: incorrectly chosen form of the model, i.e. wrong assumption as a basis for predicting assumptions about the linear nature of the change in time; the wrong accepting of the last level of the dynamic series as the reference level of the series, on which the result of the prediction will depend [13].

It should also be emphasized that these simple extrapolation methods are based on the assumption of a virtually unchanging nature of the flowing process and the absence of significant changes in the state of the external and internal environment of the prediction object, but this is not possible in practice, since the process is constantly influenced by some factors [4].

Let's consider another method of forecasting which is a trend-based extrapolation.

Generally, a trend is determined on the basis of a trend line. To determine the trend, it is enough to build a graph for the values of the studied indicator and based on it to conclude on the nature of their change. The quality of the selected model is judged by the value of the coefficient of determination: the closer it is to one (1), the better the model is.

Table 10, 11 and 12 show the trend models based on environmental performance indicators. As you can see, some trend lines predict a decrease in the amount of pollutant emissions, but there are also trends that smooth the dynamic series and predict an increase in emissions over the next two years. At the same time, the trend dependencies of the "waste generation" indicator quite accurately reflect the distribution of data and can be used for forecasting for 2019 (*F*).

Table 10. Trend models and forecast for the year 2019 as for pollutant emissions.

Dependency type	Equation	R^2	*F*
Linear	Y=-0,5687x+72,52	0,022	-
Third degree polynomial	Y=-0,1129x^3+2,6917x^2– –15,705x+84,294	0,803	23,33
Second degree polynomial	Y=-0,5252x^2+9,4099x+39,257	0,425	28,45
Logarithmic	Y=-0,598ln(x)+68,325	0,001	-
Exponential	Y=78,65$e^{-0,024x}$	0,088	-
Degree	Y=74,426$x^{-0,084}$	0,025	-

Table 11. Trending models and forecast for 2019 for hazardous waste generation.

Dependency type	Equation	R^2	*F*
Linear	Y=97262x–364101	0,62	1483877
Third degree polynomial	Y=-2327,8x^3+66500x^2– –423670x+574675	0,77	1544794,8
Second degree polynomial	Y=157,57x^2+94268x– –354122	0,62	1493852,8
Logarithmic	Y=568400ln(x)-589401	0,47	-
Exponential	Y=33,003$e^{0,663x}$	0,81	1432456,1
Degree	Y=5,9511$x^{3,9654}$	0,65	1443244,7

Table 12. Trend models and forecast for 2019 as for hazardous waste disposal.

Dependency type	Equation	R^2	*F*
Linear	Y=32694x–140168	0,71	481018
Third degree polynomial	Y=-536,09x^3+16645x^2– –112543x+160253	0,82	463037,6
Second degree polynomial	Y=1366,1x^2+6737,8x-53648	0,74	57628,3
Logarithmic	Y=182914ln(x)-199424	0,51	432556,6
Exponential	Y=10,899$e^{0,6508x}$	0,78	512345,7
Degree	Y=2,6353$x^{3,76}$	0,59	447555,2

The coefficient of determination in predicting the "utilized hazardous waste" indicator also showed a value greater than 0.5, i.e. all trend models can be used for forecasting.

As you can see, only polynomial models approximate the original series of data well, repeating the declines and recessions, but this model gives unacceptable forecast and many observations: the right branch goes up and as it is known, when increasing, t increases indefinitely.

Of course, it is almost impossible to make an adequate prediction with such a model.

In modeling, the question always arises as to how close these models are to the economic reality reflected in the time series, and to what extent the use of these models is justified for the analysis and forecasting of the studied economic phenomenon. Therefore, before making a final prediction on forecast models, it is worth assessing what kind of forecast can be expected from the resulting model in the near future, and whether this forecast can be true [14]. If the model shows the presence of extremes in the near term or an acute change in trends (sharp increase or decrease), it may be worth referring to another trend model.

For further calculation of the forecast, such constructed trend models were used, where the coefficient of determination is the biggest. Since the coefficient of determination shows the degree of change in the performance indicator due to the selected factors, in the situation of trend models – this indicator reflects how clearly the trend is observed in the time series.

Thus, comparing the obtained predicted values for 2019 by the above methods, we can conclude that polynomial trends reflect the trend of real data the most accurately, as well as the methods of regression models gave a good result in forecasting the environmental situation (Table 13). We can observe that different methods gave different models in terms of the quality of forecasts, that is, there is no universal method of forecasting.

Table 13. Comparative characteristics of the obtained forecasting results by different methods.

Method	Forecasting indicators for 2019		
	Emissions of pollu-tants	Formation of hazardous waste	Disposal of hazardous waste
The method of the average annual growth factor	11,32	1221568,28	416214,23
The method of average absolute growth	6,30	1213924,90	411963,40
Forecasting based on a fluctuating average	8,17	1363963,71	490131,25
Trend Method (Best Trend Model)	23,3	1432456,1	463037,7
One-factor regression model	16,26	-	-
A multifactor regression model	20,21	1726845	434550,1

Therefore, comparing the forecasting methods we can conclude that although not always the results obtained can be interpreted as accurate and reliable, but when it is more important to obtain predictive estimates more quickly than their accuracy, or to obtain a model as a guide for future development, which can be edited depending on the influence of other factors, not yet taken into account in this calculation, such models can also be used. Regarding the differences in the prediction results, we can say that these results would be better under stable conditions, and since the forecasting environment in our case is dynamic, it is difficult to calculate the accuracy of the forecasting, as the conditions are constantly changing, and moreover, these methods are short-term forecasting methods [11].

Unfortunately, these models do not identify ways of overcoming the environmental impact of pollutants. The models of forecasting and modeling obtained do not solve

the problem of environmental protection at the economic level, but investigate the impact of financial costs on environmental protection. The article describes known processes and the economic mechanisms for their prevention are not defined. It is desirable to pay attention to the economic aspects of these processes. The analysis of the projections will allow the implementation of environmentally balanced policies and the protection of natural ecosystems. Modeling enables employees of environmental departments or managers of regional structures to calculate the optimal state of environmental indicators for known economic or regional development factors and to trace the future trend that is required when making management decisions. Thus, the developed models in the region have shown the need to increase the cost of environmental protection, which can reduce harmful emissions and increase waste disposal.

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Model of diagnostics of resource efficiency in oil and gas sector of economy of Ukraine

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Abstract. The authors of the article determined that a number of scientists were involved in the development of a balanced system of indicators of the development of the oil and gas sector. Though an urgent scientific problem that needs further consideration is the development of a model of resource efficiency diagnostics in the oil and gas sector of the economy of Ukraine, taking into account the peculiarities of statistical monitoring. In order to solve this problem, the authors used methods of economic analysis, the method of rationing to bring the indicators to a comparative meaning, the method of additive-multiplicative compression, statistical methods of estimating variation and so on. The scientific novelty of the paper is: this study improved the model of diagnostics of resource efficiency in oil and gas sector in the economy of Ukraine based on the additive-multiplicative compression of the formed system, which, unlike the existing ones, takes into account their variation while defining weighting coefficients which show the experts' system of preferences.

1 Introduction

According to 2018 the oil and gas sector of Ukraine provided more than 40% of the economy's needs for energy resources. At the same time oi and gas sector accounted for 42.2% of total consumption. Due to high dependency, the research of many domestic scientists is devoted to various aspects of the operation of oil and gas extraction and processing enterprises.

The main tendencies of development and value of innovative technologies in the oil and gas sector were studied in [1-3].

The concept of resource efficiency in the modern and current practice of economic activity analysis has been widespread, since the efficient consumption of economic resources of any kind is associated, first of all, with intensive economic growth. That is why, the authors of [4-8] addressed the issues of ensuring a resource-efficient economy as a necessary condition for sustainable development.

Management of any economic system is always based on its current state, the definition of which is a separate scientific task. Therefore, various scientists were involved in the methodological bases of economic diagnostics, including the development of a balanced system of indicators for the development of the oil and gas sector [9-12].

This demonstrates that the scientific problem that needs to be solved in the framework of this research is the development of a model of resource efficiency diagnostics in the oil and gas sector of the economy of Ukraine, taking into account the existing peculiarities of statistical monitoring by the State statistical authorities.

The methods of economic analysis for estimation of resource efficiency, normalization method for bringing indicators to comparative appearance, method of additive-multiplicative compression for generalization of results in different directions of evaluation, statistical methods of estimation of variation for substantiation of values of weight coefficients in the model of diagnostics were used.

2 Peculiarities of the measurement of resource efficiency in oil and gas sector of economy of Ukraine

The peculiarities of the measurement of resource efficiency in oil and gas sector of economy of Ukraine include:

1. The available volume of input statistics on the basis of the State Statistics Service of Ukraine reports, with free access, significantly limits the possibilities for comprehensive assessment of the resource efficiency by all types of economic resources used in public production.
2. The change in methodology of organization of statistical observation during the recent years, and, accordingly, reporting instruments and documentation do not allow to carry out a retrospective analysis of resource efficiency indicators over a long-term period. The geopolitical changes that occurred in 2014 in the South-

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East of Ukraine resulted in temporary occupation of the Crimea and parts of Donetsk and Luhansk Regions, have undoubtedly had a significant impact on the oil and gas sector activity as well. That is why comparative analysis of the time periods cannot provide with objective information on the dynamics of the target indicators due to alterations in the special aggregate according to which they are calculated.

3. Some of the input data for 2016-2018 are not shown in the State Statistic Service reports due to its confidential status. First of all, it concerns assets conditions, volume of production and corresponding costs, fixed assets and a number of employees, financial results of crude oil production, natural gas extraction and production of refine products [13-14].

4. Any diagnostics in economic analysis is possible if there is a respective base of comparisons. In scoring models of diagnostics such a turning point are the classes of indicators stability; in the models of multiplicative discriminant analysis – the intervals of stability of integral index that determine the probability of the bankruptcy of economic entities; in the express-analysis – industry standards and cross-industry comparisons; in complex analysis – dynamics and plan value of indicators, industry standards etc. As for the oil and gas sector of the economy, for the diagnostics of its resource efficiency considering available data, we will use cross-industry comparison and analysis of time periods applying methods of statistic theory.

3 Indicators of the model of resource efficiency in oil and gas sector of economy of Ukraine diagnostics

Thus, taking into account the leading experience of analysis of economic activity [15-26] and mentioned above peculiarities of information support, a model of diagnostics of resource efficiency of oil and gas sector of the economy of Ukraine has a set of indicators as its basis, which consist of the following areas of assessment: material resources, fixed assets, labor resources and aggregate capital. Let's consider them in more detail.

1. Material resources (MR_1). Technological underdevelopment (backwardness), associated with initial processing of resources, is always characterized by low added value and high material (output) ratio. That is why effective use of material resources is the priority in the development not only of oil and gas sector, but of the economy of Ukraine. This group consists of the following indicators:

– material productivity (K_{11}) – characterizes the volume of output of the inquiry period by 1 UAH of material costs. This indicator should be maximized and is calculated by the formula:

$$K_{11} = \frac{VO_1}{MC_1}, \quad (1)$$

where VO_1, MC_1 – accordingly, volume of output and material costs in the inquiry period.

– net profit (income) for 1 UAH of material costs (K_{12}), should be maximized. According to its economic essence, this indicator is the analogue of cost effectiveness (profitability), which allows to evaluate the efficiency of raw materials and supplies in the process of profit generation in the enterprises of the industry:

$$K_{12} = \frac{NP_1}{MC_1}, \quad (2)$$

where NP_1 – net profit in the inquiry period.

– coefficient of correlation of the growth rate of product output and material costs (K_{13}). Intensive economic development involves obtaining the final result not due to the greater consumption of resource productivity. That is why this coefficient should be $K_{13} > 1$.

$$K_{13} = \frac{VPO_1}{VPO_0} : \frac{MC_1}{MC_0}, \quad (3)$$

where VPO_0, MC_0 – accordingly, volume of product output and material costs in base period.

– the share of material costs in the cost of production (K_{14}). According to 2018, material costs for the economy in general were 74,3% from the cumulative costs (total costs) for production output. Accordingly, depreciation accounted for 6,7%, labor costs – 14,1%, benefits related deduction – 2,9%, and other costs – 2,0% from cumulative costs (total costs).

As we can see, the high share of material costs – is a system problem for the entire economy of Ukraine. It indicates not only the low level of social production, but also hinders increase in wages and living standards of the population. That I why this indicator should be minimized and calculated by the formula:

$$K_{14} = \frac{MC_1}{VCCP_1}, \quad (4)$$

where $VCCP_1$ – volume of cumulative costs (total costs) for production in the inquiry period.

The main production factors which are part of economic resources, are fixed assets and labor resources (human capital). In most cases they determine the production capacity of business entities and industries of the economy in general.

According to the results of 2018, the residual value of fixed assets in Ukraine was 3783.5 billion UAH, and the volume of production – 6207.7 billion UAH. Accordingly, return on assets was 1.64 UAH. The number of employed population for the same period was 16360.9 thousand persons. Thus, the annual labor productivity was 379.4 thousand UAH per employee or 31.6 thousand UAH monthly.

Thus, complex diagnostics of the resource efficiency of oil and gas sector should include comparative assessment in these areas.

2. Fixed assets (K_2). This group includes the following indicators:

– return on assets (K_{21}) – characterizes the volume of production output for the inquiry period at the rate of 1 UAH of residual value of fixed assets, and should be maximized:

$$K_{21} = \frac{VO_1}{FA_1}, \quad (5)$$

where FA_1 – the value of fixed assets in the inquiry period.

– return on assets (K_{22}) – equals the net profit on 1 UAH of residual value of fixed assets, and it should be maximized:

$$K_{22} = \frac{NP_1}{FA_1}, \quad (6)$$

– coefficient of correlation of the growth rate of product output and fixed assets costs (K_{23}). Intensive development implies an increase in aggregate production output not at the expense of additional production capacity attraction, but due to the return on assets increase. That is why this coefficient should have the inequality $K_{23} > 1$.

$$K_{23} = \frac{VO_1}{VO_0} : \frac{FA_1}{FA_0}, \quad (7)$$

where FA_0 – residual value of fixed assets in base period.

3. Labor resources (K_3). The indicators of resource efficiency of this group include:

– labor productivity (K_{31}) – characterizes the production output for the inquiry period per one employee and should be maximized:

$$K_{31} = \frac{VO_1}{AAEP_1}, \quad (8)$$

where $AAEP_1$ – average annual number of employed population in the inquiry period.

– ROI of employees (K_{32}) – equals net profit per one employee, and should be maximized:

$$K_{32} = \frac{NP_1}{AAEP_1}, \quad (9)$$

– share of labor costs in the cost of production (K_{33}). According to statistics, in most of Eurozone countries this indicator is 30-35%, which is more than 2 times ahead of the similar level of the economy of Ukraine. That is why one of the reserves for the growth of the average level of remuneration of labor is adjustment of the production cost structure, and should be maximized K_{33}:

$$K_{33} = \frac{RL_1}{VCCP_1}, \quad (10)$$

where RL_1 – amount of remuneration of labor cost in the inquiry period.

Aggregate capital is generated from both equity and borrowed sources and is allocated to fixed assets and current assets and is also an economic resource and a focus of the researches interest in terms of its effective use.

4. Aggregate capital (total capital) (K_4). In order to characterize the efficiency of capital use, in the practice of financial analysis, along with profitability indicators, indicators of turnover and duration of turnover are calculated. Let's consider them in more detail.

– aggregate capital (total capital) turnover (K_{41}) – shows how many the income of the inquiry period exceeds the corresponding amount of the raised total capital The increase in turnover shows an increase of its use:

$$K_{41} = \frac{CI_1}{CK_1}, \quad (11)$$

where CI_1 – cumulative income of the inquiry period from all types of economic activity; CK_1 – average annual amount of capital of the inquiry period, taking into account own and borrowed sources of income.

– return on aggregate capital (total capital) (K_{42}). Any borrowed capital, involved in the activity of business entities, has its price. The condition of the expediency of its use is always the excess of return on aggregate capital (total capital) over the weighted average price of the loan. Otherwise, according to financial leverage effect, economic activity will lead to a gradual decrease in equity.

$$K_{42} = \frac{BP_1}{CK_1}, \quad (12)$$

where BP_1 – balance (gross) profit of the inquiry period, excluding income tax.

– duration of circulation of aggregate (total) capital (K_{43}) – shows how many days it will take for the income received during economic activity to be equal to the amount of attracted aggregate (total) capital Speeding up the turnover means reduction of the duration of circulation and vice versa. The formula for K_{43} calculation is the following:

$$K_{43} = \frac{365}{K_{41}}, \quad (13)$$

In the numerator, in this case, there is a number of days for the inquiry period.

Fixed assets form production capacity of the economic entities and do not directly participate in the circulation. The efficiency of the use of aggregate (total) capital is directly influenced by the turnover of the operating capital according to the formula:

$$K_{44} = \frac{CI_1}{OC_1}, \quad (14)$$

where OC_1 – average annual amount of the operating capital in the inquiry period.

– duration of operation capital turnover (K_{45}) – shows how many days it will take for the received income to be equal to the amount of operating capital and is calculated by the formula:

$$K_{45} = K_{43} \times \frac{OC_1}{CK_1}, \quad (15)$$

Thus, we have formed a system of indicators for assessing the resource efficiency of oil and gas sector of the economy of Ukraine taking into account available statistics. Taking into account that all the indicators are relative indicators we will use cross-industry comparisons for diagnostics of its condition.

By direct comparison we have an opportunity to define competitive advantages or backlog of the oil and gas sector by every indicator. However, summarizing the results of such multifactor evaluation requires the

corresponding compression based on the integrated index. For this reason, first of all, it is necessary to bring the value of all indicator of resource efficiency to one base of comparison, which means to normalize them. The current practice of rationing involves setting up values to the range [0; 1] using formula:

$$K' = \frac{K - K_w}{K_b - K_w}, \quad (16)$$

where K, K' – accordingly, input and normalized value of resource efficiency indicator, which belong to i group; K_w, K_b – accordingly, the worst and the best value of the indicator K, among other industries.

Since there are some indicators that should be maximized as well as minimized, then to determine the worst indicators K_w and the best indicators K_b we should follow the rule:
– if K should be maximized, then K_b=*max*(K), K_w=*min*(K);
– if K should be minimized, then K_b=*min*(K), K_w=*max*(K).

The use of formula (16), observing the rule, allows to arrange the normalized values of indicators in such a way that the best value of indicator corresponds with the normalized and vice versa.

With its help, each of the indicators (1) - (15) is reduced to a comparative form. The compression of normalized values to group and integral indexes is based on the additive-multiplicative model:

$$IPE = \sum_{i=1}^{n} (a_i \times K_i) \quad (17)$$

$$K_i = \sum_{j=1}^{m_i} (a_{ij} \times K'_{ij}),$$

for all $i = 1...n$,
where IPE – integral index of resource efficiency; K_i, a_i – accordingly, summary (consolidated) index of resource efficiency of i group and its weighing coefficient; K'_{ij}, a_{ij} – accordingly, normalized j indicator of i group and its weighing coefficient; n – a number of indicator groups; m_i – a number of indicators of i group.

There are certain limitations for weighing coefficients a_i and a_{ij}. First of all, their values should range from 0 to 1; second of all, the sum of coefficients of a certain group should equal 1.

4 Diagnostics of the resource efficiency of oil and gas sector of the economy of Ukraine

There are different approaches to estimating weights of coefficients, depending on the system of advantages of expert's or group of experts' who make decisions. In this study we will focus on the method which is used by the researchers while compiling different international indices with the purpose of comparison, in particular, international ecology efficiency index [14-15].

In particular, we will proceed from the fact that in order to ensure equal influence of individual indicators on group, their root-mean-square deviations considering the weighting coefficients must be equal each other: $\sigma(a_iK_i) = \sigma(a_jK_j)$, for all $i \neq j$, or $\sigma(a_{ij}K_{ij}) = \sigma(a_{ij}K_{iz})$, for all $i = 1...n, j \neq z$.

If, according to experts' preferences, individual indicators should have different impact on the group or integral index of resource efficiency, this should also be respectively reflected in proportion between root-mean-square deviation of these indicators taking into account their weighting coefficients.

Considering the mentioned above information, we have obtained a system of equations using numerical method for diagnostics of resource efficiency in oil and gas sector in the economy of Ukraine, taking into account equal influence of indicators, which allowed to present a more detailed equation (18):

$$\begin{aligned}
IPE &= 0.328K_1 + 0.261K_2 + 0.244K_3 + 0.167K_4 \\
K_1 &= 0.162K_{11} + 0.267K_{12} + 0.452K_{13} + 0.119K_{14} \\
K_2 &= 0.325K_{21} + 0.318K_{22} + 0.358K_{23} \quad (18) \\
K_3 &= 0.290K_{31} + 0.354K_{32} + 0.356K_{33} \\
K_4 &= 0.183K_{41} + 0.241K_{42} + 0.191K_{43} + 0.210K_{44} + 0.174K_{45}
\end{aligned}$$

In determining the weighting coefficients in equation K_1, the variation for each indicator was: $\sigma(a_{1j}K'_{1j}) = 0.036$ for all $j = 1...4$; in the equation K_2 – $\sigma(a_{2j}K'_{2j}) = 0.085$ for all $j = 1...3$; in the equation K_3 – $\sigma(a_{3j}K'_{3j}) = 0.068$ for all $j = 1...3$; in the equation K_4 – $\sigma(a_{4j}K'_{4j}) = 0.048$ for all $j = 1...5$; in the equation IPE $\sigma(a_iK_i) = 0.321$ for all $i = 1...4$.

As oil and gas companies are a part of mining and processing industry, it is appropriate to use cross-industry comparison with these industries and with the economy in general.

Taking into account the developed model (18), the results of diagnostics of resource efficiency for 2015-2018 are presented in table 1.

In the table 1 the symbol "*" marks the types of economic activity which are a part of oil and gas sector. As for the separate crude oil production and natural gas extraction, and refined products production in 2018 as well, the access to the relevant statistics is limited due to their confidential character.

5 Conclusions

Analysis of the dynamics of oil and gas production shows that during 2015-2018 these enterprises significantly improved their indicators of resource efficiency on all the areas of research, resulting in an integral index increase from 0.404 to 0.658, which is positive. Significant qualitative shifts occurred in consumption of raw materials and supplies and labor resources use. The result of such changes was that the oil and gas sector outperformed both the primary (extraction) industry and the entire industry, as well as the average level in the economy of Ukraine in terms of resource efficiency. Thus, on the one hand, we had a positive trend in resource efficiency increase. On the other hand, it was achieved by a significant increase in product prices in recent years.

Table 1. The results of diagnostics of the resource efficiency of oil and gas sector of the economy of Ukraine according of data of 2015-2018 years.

Industries of the economy	Years	P_1	P_2	P_3	P_4	*IPE*
Total	2015	0.293	0.345	0.260	0.306	0.301
	2018	0.316	0.388	0.334	0.466	0.364
Industry	2015	0.281	0.360	0.233	0.540	0.333
	2018	0.297	0.435	0.327	0.661	0.401
Mining industry (primary sector) and quarrying	2015	0.300	0.382	0.283	0.483	0.348
	2018	0.391	0.468	0.500	0.670	0.484
Crude oil and natural gas production*	2015	0.372	0.406	0.266	0.666	0.404
	2018	0.667	0.468	0.786	0.751	0.658
Crude oil production*	2015	0.276	0.252	0.252	0.500	0.301
Extraction of natural gas*	2015	0.448	0.548	0.320	0.785	0.499
Provision of ancillary services in the field of oil and natural gas*	2015	0.306	0.252	0.345	0.577	0.347
	2018	0.300	0.735	0.395	0.861	0.530
Processing industry	2015	0.272	0.387	0.213	0.609	0.344
	2018	0.285	0.542	0.300	0.748	0.433
Production of oil processing*	2015	0.255	0.503	0.223	0.733	0.392
Gas production, distribution of gaseous fuel through local pipelines*	2015	0.312	0.593	0.366	0.190	0.378
	2018	0.243	0.285	0.350	0.195	0.272

Regarding the oil and gas refining, as well as gas distribution system we can observe that according to the indicators of fixed assets and capital use there is a significant lag from other enterprises of the processing industry and average level in the economy in general.

Thus, the diagnostics of resource efficiency of oil and gas sector pointed to existing problems faced by refinery enterprises and significant improvement in oil and gas production field.

This study improved the model of diagnostics of resource efficiency in oil and gas sector in the economy of Ukraine based on the additive-multiplicative compression of the formed system, which, unlike the existing ones, takes into account their variation while defining weighting coefficients which show the experts' system of preferences.

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Management of changes in the insurance industry in the conditions of climate crisis

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Abstract. The insurance industry is rather effective in overcoming consequences of natural disasters. Insurance companies play a key role in financing natural disasters consequences, at the same time they sustain record losses and are in difficult financial conditions. Taking into account the above said, the issues of management of insurers risks is up-today and is connected with climate change. In article the content of "climate risk" as risk is specified, the emergence of which is caused by human activity, which leads to pollution, resulting from industrial activity and other sources that greenhouse gases (carbon dioxide) which are capable to absorb a range of infrared radiation generate and, as a result, predetermine warming of the global atmosphere that brings to change of structure of the world atmosphere and adds natural climate instability during the certain periods of time. The most destructive dangers threatening to mankind owing to global warming are systematized. Types of risks and their sphere of manifestation in Ukraine are outlined. The directions of adaptation of the insurance industry to changes, caused by climatic crisis are defined. Due to results of the research, the theoretical generalization and author's solutions of a scientific task are offered, which appear in the development of scientific and methodical approaches and justification of practical recommendations about modernization of activity of insurance companies and reinsurers in the conditions of risks, generated by global climate changes. Scientific novelty of the research: specifying the role of the insurance industry regarding the prevention of risks connected with global warming.

1 Introduction

The climate change process, mainly because of its influence on the environment, has destructive consequences which mankind faces now and will face in the future. Risks of natural disasters and climate change draw the main attention of world politicians and mass media now.

The climate change does rather a significant effect on the activity of insurers as new insurance risks appear, the sizes of the insured losses are growing owing to natural disasters that forces insurers to raise insurance rates. As the growth of intensity of extreme weather conditions is observed, the risk of harming of property and human lives is also increasing. In this regard for insurance companies the climate change – is rather a threat, than an opportunity for business development. Therefore insurance companies need to adapt to climate change, predicting how climate changes and their consequences will affect the insurance risks of their clients. For this purpose, it is necessary to estimate risk and to revise some corporate procedures (pricing, conditions of the signing of the contracts, etc.) taking into the consideration the tendency of the insurer to risk, depending on a field of activity, geographic location, the existence of opportunities and conditions for business and other factors. Many initiatives at the international and national levels are devoted to the solution of this task.

The aim of the research is the definition of the directions of adaptation of insurance companies to changes in a profile of the risks caused by climatic crisis.

2 Results

The term "climate" occurs from Greece and means area and in a common understanding connected with weather conditions of the region that are recorded for a long time. The climate characteristics are average quantity of annual rainfall (rain, snow, etc.), the maximum and minimum temperatures throughout all season, the number of the sundial, humidity level, frequency of extreme weather conditions, etc. Thus, climate is understood as statistics of weather conditions within a decade and more [1].

The concept of "climatic changes" is used for the characteristic of global changes in the climate, long-term changes of average planetary temperature or is used for demonstration of changes of weather conditions, which occur at the local and regional levels. Thus, climatic changes are large-scale long-term changes in weather conditions of the planet or its average temperatures [1]. Such changes are straight lines or the mediated consequences of human activity that lead to change of structure of the world atmosphere and add natural inconstancy of climate during certain periods of time. In the context of the definition given above, human activity

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is pollution which results from industrial activity and other sources that generate greenhouse gases (carbon dioxide) which are capable to absorb a range of infrared radiation generate and, as a result, predetermine warming of the global atmosphere.

Nowadays, the negative consequences of climate change consider a threat to security, putting it on one step with the terrorism threats. Researchers insist on necessity to refuse from the term "climatic change" and thus to continue supporting the opinion that it is a passive problem that does not demand urgent intervention. However, it is necessary to use the concept "climate crisis" that gives the understanding that it is not a problem of the long-term future, but danger which needs to be prevented already today. And the Swedish activist Greta Tunberg, called the changes happening in a climate of the planet – climate ruin or climate emergency situation.

The term "climatic changes" was entered into scientific and political use by the geophysicist Wallace S. Broker, having published in 1975 the first thorough work about global warming and if more precisely, then – heatings, under the name "climate changes: or are we on the verge of pronounced global warming?" and rather long time, the term" global warming "was widely used. However, in the next decades the description of increase in global temperature, changes of weather and atmospheric conditions were changed to the more neutral term "climate change" which allowed to soften perceptions of the existing problem, connected with global "heating". Use of the term "global warming" is more accurate from the technical point of view as it characterizes changes in the power balance of the planet. Such an approach allows us to speak about risk, but not about uncertainty.

Climate changes should be perceived as the emergency situation and terms which are used for its designation have to reflect the degree of sharpness (urgency). According to scientists' research, the mankind has about 10-12 years to prevent climatic crisis. For this reason, they consider that it is correct to speak about risks of safety, and climate change should not be considered as mainly external. Climate changes reveal the risks inherent in modern society that cause dangers [1]. Only such understanding of the essence of climate risk reflects cause and effect, understanding of which allows to react adequately" to the multifaceted characteristics of climate risks, connected to the safety of people and societies" [2].

In table 1 is given characteristic of agreements in the sphere of global heating which Ukraine has joined.

Thus, we can observe a certain evolution in the understanding of problems, related to climate change. If in "The Rio Convention" generally questions were linked to ecology, then the Kyoto Protocol contains obligations for the countries on the search of mechanisms of reduction and stabilization of greenhouse gases. However, the mechanisms found were commercialized – the countries with low economic development began to trade with its greenhouse quotas, therefore such an approach did not help to achieve goals – decrease of the concentration of greenhouse gases.

Orientation to the development of "green" power was another moment of the Kyoto Protocol. In many countries of the world including Ukraine, businessmen that developed "green" power received extraordinary preferences from the governments. As materials of the World Meteorological Organization (WMO) showed – preferential development of "green" power did not give tangible results in the fight against greenhouse emissions [3]. Therefore, according to the Parisian agreement until 2020 the long-term plans had to be developed, in order to provide concrete steps in the sphere of decrease of greenhouse gases in emissions and prevention of global "heating".

Table 1. Agreements in the sphere of global heating which Ukraine has joined.

Agreement	Date of signing	Content
The Framework Convention on Climate Change – "Rio Convention"	9th of May 1992, New York	The agreement between the countries that provides prevention of dangerous anthropogenic impact on climate of Earth. Emphasis on the conservation of biodiversity and steady use of its components.
The Kyoto Protocol is the annex to "Rio Convention"	11th of December 1997, Kyoto	The participating countries agreed during 2008-2012 to reduce and stabilize the level of emissions of greenhouse gases to the level of 1990
The Parisian agreement – the additional document to "Rio Convention"	12th of December 2015, Paris	Commitments as for reduction of emissions of greenhouse gases undertake all countries irrespective of the level of economic development.

The Conference on climate (COP25) was held during two weeks of December 2019 in Madrid (Spain). The UN Secretary-General Antonio Guterres, in the report, emphasized that the mankind can move in two ways: "As sleepwalker and to pass a non-return point, thereby to put under the risk health and safety of each and one person of the planet" and" by hope" which provides efforts in the direction of controlling increase in global temperature within 1.5 °C and to the middle of the century to reduce emissions of greenhouse gases to zero, having refused use of fossil fuel [4]. The secretary-general emphasized that the main subject of the World Economic Forum in Davos in 2020 will be the problem of strengthening of climatic crisis and loss of biodiversity, as temperature records and natural disasters became the main manifestations of global warming in 2019.

The relevance of this perspective is shown also in the report of the World Economic Forum (WEF) prepared. According to data, the presented in the document, more than 50% of world GDP is dependent on state of environment that makes about $44 trillion in absolute figures [5]. The experts call industries such as constructions – $4 trillion, agriculture – $2.5 trillion, production of food and drinks – $1.4 trillion are the most dependent on climate changes. As their activity or depends on resources that are received from the environment or are based on services that are received from ecosystems – clear water, fertile soils, pollinations and stable climate. In case of impossibility of receiving by

these industries from the environment raw materials and services, they experience enormous losses. So, according to the data of the report of WEF (Global Risk Report 2020), the most dependent on climate industries produce 15% of world GDP – about $13 trillion and 37% which are moderately dependent makes $31 trillion.

Also WEF submitted the list of 10 main dangers which may threaten humanity in 2020, nine of which are connected with climate change. These risks were estimated by two criteria – the most potentially destructive and the most probable (table 2).

Table 2. The most likely and most devastating threats to humanity.

Most likely	**The most potentially destructive**
Extreme weather	Climate change inactivity
Inactivity is in connection with the change of climate	Weapons of mass destruction
Natural disasters	Loss of a biodiversity
Loss of biovariety	Natural disasters
Environmental disasters are provoked by the humankind	Water crisis

Source: powered by [6].

All of this is a confirmation that climate changes threaten social and economic stability and need a search of ways of its minimization and elimination. The formation of strong economy and creation of social stability is a question of global interest – and the steady future has to become the collective choice.

Taking into the consideration specific nature of activity, insurers especially understand that warming of climate for more than 2 degrees can lead to extremely high risks of impact on the environment and impossibility to provide customers with available insurance products.

Based on results of ranging potential threats behind the probability and the consequences presented by Willis Towers Watson's Thinking Ahead Institute, it is identified the three of new risks for insurers, namely climate risk, the Cyber risk and political risk.

Climate risk is a degree of probability of adverse weather during the certain period of time [7]. Naturally climatic and social aspects of risks are marked out in the system of global climatic changes [8]. Examples of realization of the risks generated by climatic changes are represented in the table 3.

Nowadays in Ukraine climate risks are manifested in the spheres of agriculture, energy and health care and also influence on the quality of water sources of country (table 4).

As Ukraine has agro-industrial specialization, the most notable influence of climate risks will be on agricultural production. According to experts conclusions, within the next 10-15 years our country will face threat of 25% loss of productivity of soils that will turn out to be consequence of temperature change and an amount of precipitation that in total with exhaustion of soils and escalation of extreme weather conditions will lead to a critical situation [11].

Table 3. Type of risk and its manifestations.

	Type of risk	
	social	socio-political
Manifestation	increase of death rate from strengthening of heat-waves	increase of migratory streams of population (appearance of ecological or climatic refugees)
	expansion of a zone of inoculable diseases	humanitarian problems (deficiency of food, drinking water)
	increase in the health risk (increase in incidence and death) some social groups of the population	

Source: powered by [9, 10]

Growth of frequency and consequences of the natural disasters caused by climatic changes threaten life and health of humanity their property safety, worsen food security, so has a negative effect on global economic development. All this demands existence of adaptable mechanisms which make society steady to the consequences caused by climate change. Adaptation to climate changes is an increase of ability to be restored from consequences of catastrophic events, that is decrease in vulnerability and increase in financial and physical resistance to disasters. Insurance mechanisms are suitable in both aspects of adaptation to climatic changes.

Their realization occurs on two vectors:

1) through formation of insurance funds proving receipt of financial resources for payments of compensations to citizens and on restoration of infrastructure after the disaster insured event happened. Without properly organized insurance protection a burden of payment of losses lays down on certain citizens, the governments or the organizations assisting and it significantly presses on budgets of the state that finally leads to economic and social difficulties for injured;

2) by informing society on the nature of the risks generated by climate change and assistance of realization of actions for improvement of protection against the disasters caused by climatic changes. Experience of insurers becomes useful at risk assessment of approach to a concrete event and its consequences or to consider during selection ways and sites.

Effects of climate change on world economy are presented on figure 1.

The insurance market plays a huge role, helping to soften consequences of natural disasters and to react to them that demands complete survey of the new risks which are on the agenda for insurance companies.

The countries that have broad coverage of insurance protection recover from consequences of natural disasters much quicker. The governments of economically developed countries understand a role and benefits of insurance upon natural disasters, though, so far a large amount of risks remains not covered by insurance, so there is "a gap in protection".

Use of insurance mechanisms in the conditions of climate change is the transition from climatic crisis to management of climate risks providing conditions of social and economic stability of society.

Table 4. Spheres of manifestation and consequence of climate risks in Ukraine.

	Sphere of manifestation of climate risk			
	agriculture	*water resources*	*energy sphere*	*healthcare*
consequences	- losses of a harvest; - changes of periods of ripening of agricultural cultures; - an increase of their vulnerability is to the wreckers; - resource depletion: losses of the fertility of the soil, desertification, erosion etc.	- violation of the hydrodynamic mode and water balance of the rivers; - degradation of water resources, related to the changes of the water mode, exhaustion, contamination through the surplus loading.	an increase of demand on electric power during a summer heat; complication of functioning of objects of hydroenergetics through changes in character of precipitations and river flow; negative consequences are from the extreme weather phenomena;	- increase in the number of victims of heatstroke's; - worsening of health of urban population through superficial contamination and changes in an ozone layer; - increase of level of death rate as a result of cardiovascular diseases; - increase of allergic and asthmatic diseases of drying out of peat bogs in the north of Ukraine and Polesye that will entail frequent fires; - increase of intestinal and infectious diseases as a result of worsening of quality of drinking water; - allergic reactions are as a result of bites of insects from Africa, Near East and Mediterranean, and also poisonous spiders east; - appearance of malaria, fever of Riphtali and other infectious diseases; - growth of quantity of cases of diseases of tick-borne borreliosis (Lyme's disease) and tick-borne encephalitis owing to increase the number of pincers; - emergence atypical earlier for Ukraine and increase in quantity of cases of already known infectious diseases (HIV / AIDS, Hemorrhagic fever with renal syndrome, hepatitis C, atypical pneumonia, COVID-19 and others) owing to increase in a flow of climatic refugees.

Source: powered by [9, 10, 11, 12]

As a result of adverse effects of climate change, insurance business faces large-scale insurance losses. On the agenda there are questions of risk management of insurers, relate to climate change – all potential risks which can influence on the companies, regions, the countries or mankind in general. In the long term, in the absence of activities for adaptation to consequences of global warming insurers will be forced to raise the prices and for millions of people insurance protection may become inaccessible. For the purpose of prevention of such situation it is necessary to study physical risks and to develop adaptation measures for minimization or neutralization of their action.

The growing frequency and weight of natural disasters that is a consequence of climatic changes, in the short-term period can lead to increase in receipts of awards, but in the long term can be financially excessive for insurers. In this regard experts determine the major factors limiting desire of insurers to take risks which are connected to the climate change on insurance:
- almost unpredictable consequences of global warming;
- increase in oceans level;
- increase of intensity of natural disasters.

In work "Insurance for climatic adaptation: opportunities and restrictions" [13], presented to the Global commission on questions of adaptation, authors are formulated recommendations to receive the maximum benefit from insurance in the course of climatic adaptation:

1) Invest in models with the open code which provide the long-term review of climate risk and the reference to insurance decisions.

2) Development of united politics, so to implement models of climate risk in the basis for national strategy of adaptation.

3) To develop coherent regulations and standards of climatic adaptation in different countries.

4) To promote an innovation in the sphere of insurance which can react to the changing climate risk.

5) To strengthen dialogue between insurers and developers of policy around "To make it better".

6) Convergent programs of insurance, humanitarian aid and development.

7) Promoting and investments of money in literacy of society [13].

Based on the results, presented in Global Risk Report 2020, the main threats to security of mankind are climate crisis, reduction of biological diversity and record extinctions of different types of plant and animal. Owing to human activity 83% of all wild mammals and a half of plants already disappeared from the planet that threatens nutrition and health systems.

About 78% of the experts participating in polls by preparation of the report noticed that they expect a strengthening of economic confrontation and internal political split in the certain states in 2020 that will have catastrophic consequences, especially for the environment [5].

Top 5 the largest risks which threaten to the planet in the next ten years are related to ecology among which: extreme weather conditions which lead to death of people and loss of property; a policy failure mitigation of the consequences of climatic changes from the governments and the large companies; an anthropogenic threat to the

environment and environmental crimes; loss of a biodiversity and destruction of ecosystems; big natural disasters like earthquakes, a tsunami, eruptions of volcanoes and geomagnetic storms.

According to the world meteorological organization, average temperatures of the periods of five (2015-2019) and ten years (2010-2019) are highest during the entire period of observation (fig. 2).

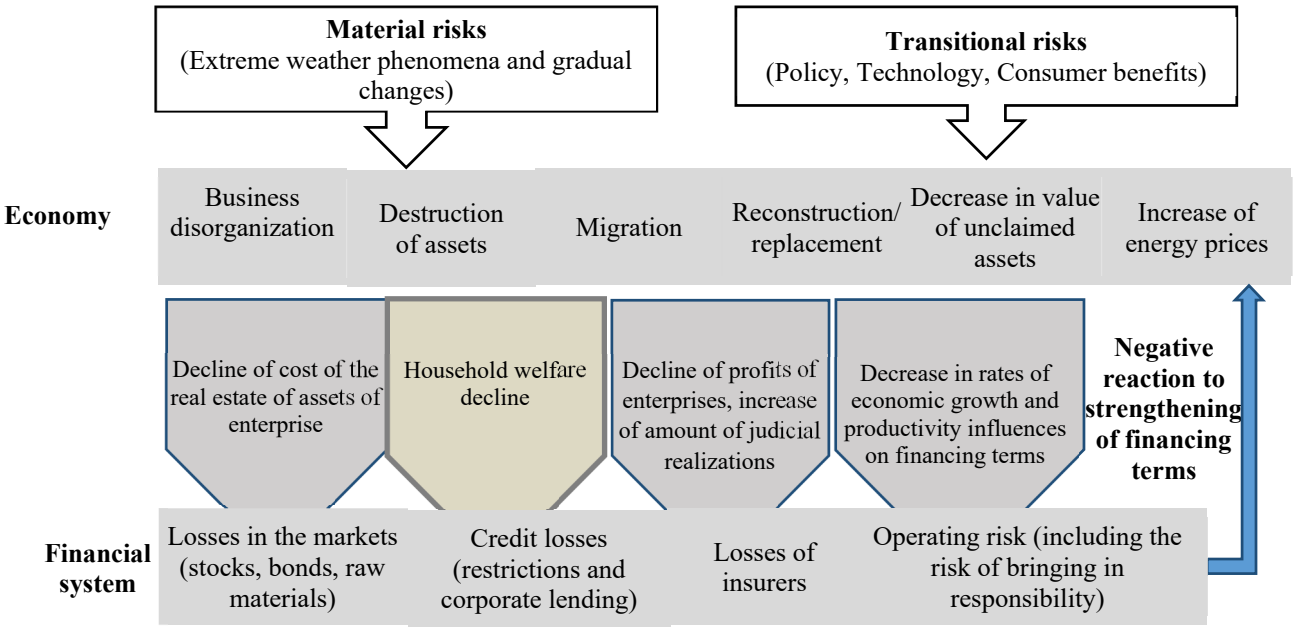

Fig. 1. Material and transitional risks for global economy from climate changes.

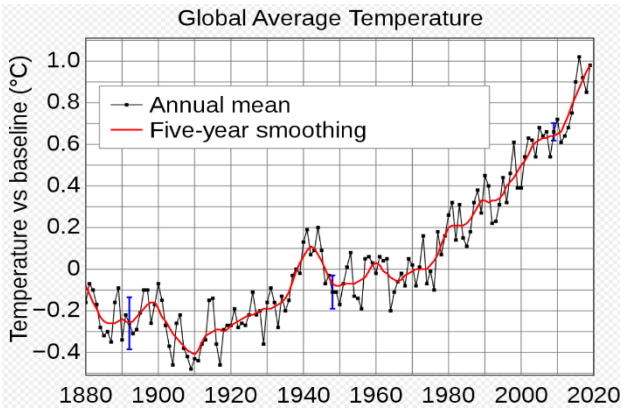

Fig. 2. Changes of global average temperature over the land and the ocean during 1880-2015, concerning average temperature for 1951-1980. Note: By black line is designated average annual and by red – moving average in 5 years. *Source*: Institute of comic researches of Goddard in NASA [14].

Since 2016 the highest economic losses were recorded from natural disasters during the last five years in the world: and the general losses in the economy made $175 billion; the insured losses exceeded $54 billion (against $94 billion and $38 billion respectively in 2015). As we see, both graphics correlate among themselves from what we can make a conclusion – an increase in global average temperature over the land and the ocean is one of the reasons for the growth of the number of natural disasters, since the 90th years of the last century.

According to forecasts, by 2030 economic losses will exceed 3% of global GDP (depending on the level of development of the country, this indicator can be from 3.2% to 11%).

In the central part of the USA, Northern Canada, Northern Russia, and Southwest Asia were observed abnormally high rainfalls. An average amount of precipitation in 12 months in the USA from July, 2018 till June, 2019 (962 mm) was maximum for all history of observations.

Climate changes are generated by "secondary dangers", such as local floods, heavy rains, long drought, strong wildfires, and other extreme weather conditions. Losses from "secondary dangers" grow because of rapid development in areas that are affected by difficult weather conditions and more high temperature [15].

Thus, the given examples, demonstrate that climate change is potentially serious threat for world economy, as a result of action of direct and indirect risks which lead to decrease of the level of global danger, related to food security and access to drinking water, safety in the sphere of energy, risks for life and health of population, stable existence of ecosystems.

According to Swiss Re Institute researches, insurers worldwide in 2019 paid 49.59 billion dollars on losses connected to the extreme natural phenomena (fig. 3).

In the 1980th years, the annual sum of payments on its losses was about 5 billion dollars a year. The agro-food industry, construction, trade, power, tourism, and the transport sector are the most strongly inclined to these risks.

We constructed a linear model by data factors and revealed certain regularities and dependences by consideration of dynamics of the number of accidents of natural-science character, losses from accidents and insurance losses (fig. 4).

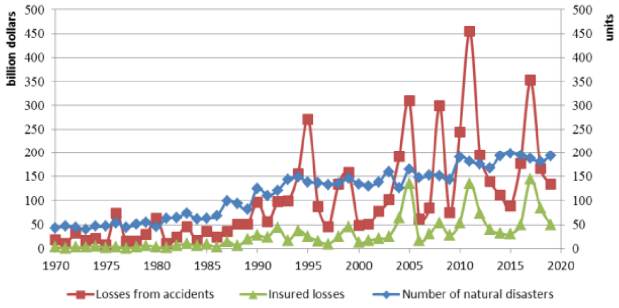

Fig. 3. Dynamics of the number of natural disasters, losses from accidents and the insured losses during 1970-2020. In the world, one billion US dollars. *Source*: powered by [16].

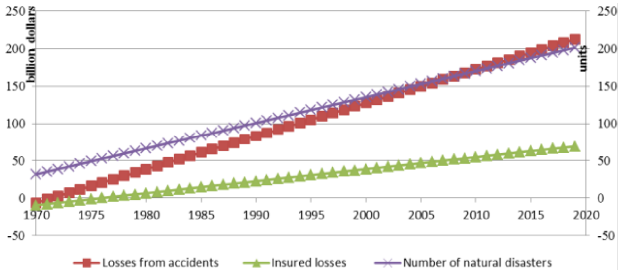

Fig. 4. Trends of number of accidents of natural-science character, losses from accidents and insurance losses. *Source*: powered by [10].

Losses from accidents correlate with the number of accidents. From figure 4 it is visible that the gap between losses from accidents and losses that were insured and, respectively, were compensated by insurers increases. Insurance losses lag behind losses of accidents that indicates lack of attention of participants of the insurance relations to possible mechanisms of protection against the losses caused by such risks. Insurance companies undertake carefully risks as the probability of their ruin grows.

Thus, climate change is a serious threat for the world economy that forces insurance companies to refuse traditional approaches to risk assessment and also to raise rates because of the inability to estimate the probability of natural disasters. The standard approaches to risk assessment that are used in insurance, are based on the analysis of historical data, but modern practice demonstrates that nowadays they are insufficient, and risks connected to natural disasters, more often even not accepted on insurance by insurers. There is an increasing number of non-insurance risks in the world, and the main reasons for such state of affairs are the unpredictability of the effects of global warming, an intensification of natural disasters and raisings of global ocean level.

The role of insurance companies in opposition to climate changes is carried out in the directions:
- compensation of consequences of natural phenomena;
- participation in the organization and financing of preventive actions; financing of economy by long-term investment (for example, the Swiss Re undertook the obligation to transfer the investment portfolio to clean zero emission of greenhouse gases to 2050 and entered TOP-5 of brands that got approval from NGOs in 2018 because of climatic actions);
- stimulation of insurers to the reduction of emissions of carbon dioxide;
- modification in insurance programs for the purpose of reduction of emissions of greenhouse gases; investments into renewable energy sources.

However, the development of methods of measurement of economic losses from climate change is not finished yet. Insurers have an opportunity to estimate short-term losses from change of weather characteristics, more frequent and more and more destructive natural disasters, but the main part of potential costs does not fit into a framework of the standard economic analysis. Scales of economic consequences of climate change, most likely, will grow, though not smoothly. What is especially important for future generations, that degree of damage will depend on what measures of policy will be adopted for protection against consequences of climatic changes today.

Such trends transform also the role of global insurers and reinsurers in the conditions of climate change changes. The considerable sums are allocated to the development of decisions for overcoming the growing risks [17], connected to climate change and for reduction of a gap in insurance. The saved-up statistical data constructed by insurers of the model of spontaneous accidents facilitate risk assessment. Besides, insurers carry out activity and at directly informing and increase in awareness of business and communities on risks for the purpose of strengthening their stability. Using the latest technologies, insurers can and improve the opportunities of modeling of risks and develop new decisions for primary and secondary dangers to help to reduce uninsured risk of an accident. Restriction of global warming requires participation of “all society”. Cooperation between insurance companies, reinsurance, and the public sector can make the world steadier, more compatible with life, growth, and development. The influence of the effects of climate change becomes more and more noticeable and significant, but at the same time, it opens great opportunities. Thanks to cooperation more practical and reliable models of insurance can be introduced and realized.

Insurance companies around the world not only make changes to the programs for the reduction of emissions of greenhouse gases but stimulate insurers to reduce emissions of carbon dioxide and also are engaged in investment into renewable energy sources. Insurers support the implementation of new technologies, insuring risks of introduction of innovations, related to renewable energy and other areas.

The national governments, regulators, and businesses have to fight together effectively against climate change and accelerate the transition of a society to renewable economy, seeking for use of reduction in carbon technologies.

Insurers and reinsurers take part in the fight against climate change in such directions: inform society on risks of global warming, compensate consequences of natural disasters, participate in the organization of precautionary actions and finance economy by long-term investment.

Insurance is only one of the available funding mechanisms for natural disasters. However, this process

is necessary to consider in a wider fiscal framework which also includes international aid, reduction of debt, use of other financial securities, the formation of reserves of accidents and government budgets. Besides, insurance and other funding mechanisms for risk of natural disasters are only a part of the decision, they need to be integrated into other actions concerning stability and adaptation as a part of the complex strategy of adaptation to climate change. Therefore insurance products are connected to climate risks, and can act on micro, meso- and macro-levels.

1. Micro-insurance is the direct insurance of individuals or insurers of small businesses. However, more often microinsurance means development micro products for insurance of the most vulnerable persons in the countries with low-income level; The Parallel with the concept of microfinance.
2. Meso-insurance refers to those situations in which the insured is not an individual, but rather an aggregation of individuals under a collective body. For example, the insured might be an organization that supports a collective of farmers within an area. This meso-level organization buys an insurance product designed to cover the collective of individuals; the individuals themselves are indirect beneficiaries of financial protection. They will receive payments from the meso-level organization, based on any claims paid to the organization through insurance.
3. In macro-insurance the insurer, as a rule, is the state subject, such as government which pays an insurance for ensuring payments in case of national accidents, such as a flood or a tropical storm. Payment for the state product can be used for various purposes on behalf of the population of this country. For example, payments can be used for the public services so that they could support further the help owing to accidents.

3 Conclusion

Climate change carries out notable consequences for the sector of insurance and reinsurance. In the world where the climate risk grows, financial protection becomes even more important even if the costs of it also grow. Thus, insurance products, services in reinsurance and securities – all these are examples of financial shock-absorbers concerning the risk of climate change, but at the same time, their use can encourage changes in the behavior of society for the purpose of slowing down of negative changes of global climate.

A search of the balance between ensuring the availability of services and management of financial stability can become tougher for insurers if extraordinary weather conditions continue to amplify. Adapting insurance management to climatic anomalies, insurers have to concentrate on:

- strengthening of risk assessment, related to climate, at the same time, using long-term measures for reduction and mitigation of such impacts;
- use of complete approach to risk management, related to climate, integrating them as a part of the efforts on risk management of the company;
- introduction of actions, in order to show better the readiness for climate changes to regulators, analysts, and customers;
- development of innovative solutions by insurers, related to climate changes.

These measures can help insurance companies and regulators to create more equal conditions and a stable market for all interested parties.

Key conclusions of research can be presented by such theses:

1. Climate change enhances economic risks for insurers.
2. Large insurance companies develop new approaches to the assessment of risks of the approach of extreme weather conditions and make corresponding changes to insurance contracts.
3. New services in the insurance market are intended to support environmentally friendly technologies; however, insurance companies pay close attention to problems of adaptation to the risks caused by global warming.

Thus, traditional understanding of a role of the insurance industry in fight against consequences global heating changes. There is a transformation of understanding a role of insurance companies – transition from traditional insurance mechanisms to realization of preventive function of insurance, collecting and providing data as for changes of temperatures, quantity and force of natural disasters, informing society about threats of carbon use, and restriction of insurance of productions, which use fossil fuels.

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Geographic particulars of the world's population food ration

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Abstract. The research of a human food ration is caused by the great social significance in solving the problem of proper supply the population with food in the world countries. The food problem has a most evident geographic character. The world countries having at their disposal various agro-climatic conditions, demographic resources and population growth rates, socio-economic potential, specialization and labor productivity of agriculture production, are essentially distinguished by the food supply level of population and by structural characteristics of food ration. The formation particulars of the world countries population food ration were considered and characterized in the article. The key characteristics and factors of the world population's food ration were analyzed there. The geographic differences of food ration, as well as the world countries typology by distinctive features of food consumption through their division into groups (nutrition types) according to the content and quantity of basic components in food ration were determined in it.

1 Introduction

The actuality of the food problem research is preconditioned by its great social significance. Under the present conditions the problem is not placed on the same footing as merely a food shortage, the issue of quality, variety and structural balance of consumed food products, as well as their excess consumption and the consequences caused by it, arises acutely.

The food problem has the most evident geographic character. The world countries having at their disposal various agro-climatic conditions, demographic resources and population growth rates, socio-economic potential, specialization and labor productivity of agriculture production, essentially distinguish by the level of population food supply and by structural characteristics of food ration.

Looking for the ways of smoothing the international differences in the population food provision remains the actual direction of socio-economic geography research. At the same time, the old scientific methodology arsenal, having lost its role in explaining the present-day processes, especially at the global level, is not able to disclose the essence of changes, which are taking place. In this connection, a new approach is required for solving the most adequate spatial representation of food problem in the world countries, which demands applying up-to-date research methods (geo-information system-technologies, mathematics-statistical apparatus, etc.).

The purpose of this research is to determine the main geographic differences in food ration of the world population and analyze the factors of its formation.

2 Literature review

The research is based upon the official data of World Health Organization and the UN Food and Agriculture Organization [1, 2].

As long-term experience shows, the problem of nutrition has been always notable by its acuteness. From the works of the well-known Persian polymath Ibn Sina we have got evidences about important significance of the study food ration, which was paid to by naturalists and physicians throughout the world.

Hence, truly scientific interest to food as a part of a nation's culture emerged in the second half of the XIX century. In the works of this period a factual-descriptive approach prevails. Some piecemeal information about food ration of this or that nation could be found in the works of I. Zabelin, N. Kostomarov [3] and others.

The formation of the theoretic-methodological line in the study of food ration as the world nations cultural phenomenon is linked with the research activities of C. Lévi-Strauss [4], R. Bart [5], J. de Kastro [6], V. Pokhliobkin [7], V. Nikolenko [8], V. Smoliar [9] and others. Observations of food ration in the world different regions allowed considering it as a culture's specific sphere that exists in relations of mutually associated historic-geographical, social and cultural context.

Geographic trend in researching food ration of the mankind was developed by J. de Kastro [6], H. Kariel [10], J.-R. Pitte [11], D. Bell [12], A. Colombino [13], P. Mullie [14], T. Lallukka [15], M. Sorre [16]. Various approaches to defining the typology of countries and regions with relation to their population's food ration character, were proposed by the researchers. Thus,

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H. Kariel compiled the world map distinguishing "wheat", "rice", "maize", "millet-sorghum" and some other nutrition types of less importance and the corresponding legend to it having determined the main sources of calories and the main sources of protein for each geographic "type of nutrition".

But as it is stated by many researchers, the substantial changes in ration and food nourishing value for the world population are taking place under the present-day conditions [17].

This circumstance gives grounds to speak of insufficient study of geographic aspects of territorial food ration differentiation of the world population and the factors that change it. This determines the need of performing further regional exploration of this food problem by geographers.

It is scientifically proved, that the basic components of a human food ration are such nutrients as proteins, fats, carbohydrates, mineral salts, water, microelements and vitamins. Food-staffs contain over 600 nutritive materials that are necessary for normal life activity of human organism, they can be united into four groups: bread and cereals; vegetables and fruit; meat, fish and dairy produce; fatty and sweet foods. Each of these nutrients occupies its place in a biochemical process chain.

Types and traditions of nutrition are the result of long historical an organism adaptation to a particular type of food [18]. In food ration formation of the globe's population a large number of eco- and endogenic processes take place, which can be brought to the following factors: historic-cultural development, climate-geographical conditions, religious customs, national traditions, socio-economic development, cultural and trade links, science-and-technical progress, etc.

But at the same time all the variety of food forms intrinsic to the mankind can be put into comparatively small number of nutrition models which are differentiated by the characteristics of the basic sources of calories and animal protein. Within the frames of these models or their combinations there can be featured several nutrition systems which are specific for individual ethnos or historic-ethnographical regions that distinguish by a set of nutrient components [19].

Prompt detection of the steady tendencies in food products structure changing and their consumption causes the need for forming nutrition status of the particular region's population with reference to geographical, climatic and social conditions.

3 Methods

The performed analysis of territorial differentiation of the world population food ration was carried out both by using quantitative and qualitative indexes.

There is substantial gap in quantitative food consumption among the world countries (Fig. 1). The most essential gap is between food consumption and nutrition norms in the countries of Asia and Africa. According to the World Bank, over 33% of population of these countries received less than1700 kcal/person a day, and the majority of them – below 1500 kcal at the beginning of 1980s and 1990s. Nowadays this figure fluctuates within 1900 – 2000 kcal.

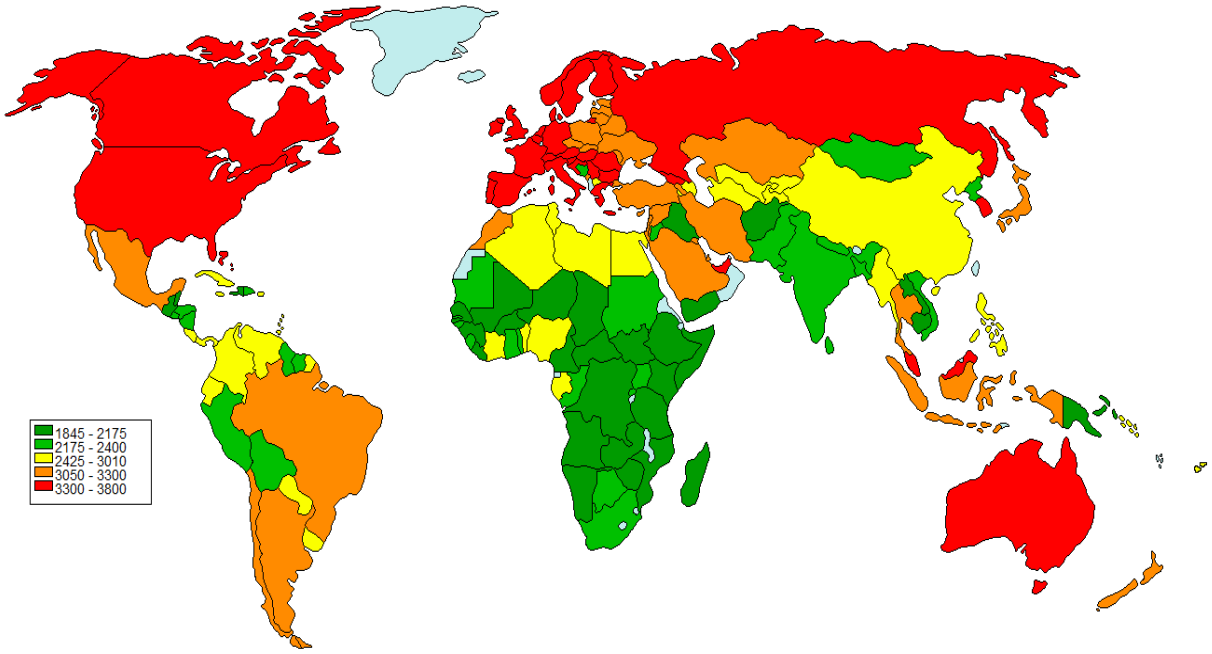

Fig. 1. Daily average per capita food consumption, kcal/person (compiled on FAO data, 2018).

Disproportion in food consumption standards especially considerable if compared to the economically developed countries and the most backward, the poorest ones, primarily in Africa. For instance, the gap in daily average food consumption by Somali population (1845 kcal/day) and Belgium (3793 kcal/day) is as much as more than twice.

High level of food consumption is typical for economically developed countries at this time. Daily human ration caloric value of food amounts to a little bit

over than 3000 kcal (except Japan where this index makes up a little more than 2700 kcal/person a day). These countries produce and consume over 3/4th of the world food, though only 18% of the Earth's population live there.

In this connection, in scientific researches a special attention is paid to the fact that more and more people in the world overeat and have body mass overweight, which causes increased susceptibility to diseases, drop in working ability and shortening of lifetime.

The countries with the lowest level of food consumption are located within so-called "hunger belt". Starting in South America, the belt covers larger part of Africa and goes on in Asia.

The epicenter of "hunger belt" is in Tropical Africa, the largest region in the world. The population in a majority of the countries, located on "hunger belt" territory, consume less than 2000 kcal a day, due to this the share of people who suffer from starvation and/or those who are underfed exceeds 40% (Chad, Somali, Uganda, Mozambique) [20].

Difficult food situation is typical for South-West, South and the South-East Asia. So, in South and South-East Asia (except China) food consumption varies from 2000 to 2400 kcal/day.

The world food consumption demonstrates the positive dynamics and has a strong tendency to increase. If in 1930s average per capita consumption amounted from 2100 kcal/day, then before the beginning of 1960s it increased up to 2300, before the beginning of 1990s – up to 2700 and in 2015 it amounted 2950 kcal/day. Maximum rates of the index growth demonstrate Asian countries, primarily China where the consumption growth made up 45% as compared to 1970. For that time, only South Asia countries and African countries to the south of Sahara did not reach daily ration of caloric value, which is specified by FAO as 2400 kcal/person.

More essential is the world countries differentiation by quantitative characteristics of food ration. Thus, by the share of the basic foods ration the characteristics differ almost by four times (from 23% in Iceland to 81% in Eritrea), and by the quantity of protein in a ration – by seven times (from 18 g/day in Iraq to 133 g/day in Iceland).

Beside high standard values of food consumption, economically developed countries are also characterized by high degree of differentiation of food consuming structure, the index of which is low dependence from basic foods (by caloric capacity this group makes up nearly 30% of total ration) and high level of animal husbandry products consumption (nearly 30% of daily caloric capacity as well). Long-term analysis of food consumption in the developed countries testifies unification of consumption structure challenged by mutual transition of national features into the international and vice versa against the background of globalization [21].

At present stage of the society development it is possible to speak of the formation food consumption structure of postindustrial type in the economically developed countries, when qualitative improvement of nutrition takes place through increasing variety of the foods consumed that have higher gustatory and nutritional properties.

Generally, one product dominates in the structure of food ration regarding nutrition of the population in the developing countries, especially in the most backward ones. For instance, for people of South and South-East Asia this is rice, its share amounts to 70% and even to 90%. For the savannah zone and Sahel in Africa the most typical are millet cultures (chiefly sorghum) which give 40-50% of daily calorie norm. In food ration of people in African continent's forest zone prevail such root plants as yam, manioc (cassava), sweet potato.

The picture of nutrition of Latin America population is more varied. In the countries with comparatively favorable food balance (Argentina, Uruguay, etc.) the ration base is formed by wheat; in the countries of Central America and in American Indians settling areas maize prevails; in tropical coastal lowlands – rice; in Paraguay – manioc; in former "banana" republics of American "isthmus" – banana; in Cuba and Haiti – cane-sugar, etc.

The picture of the world population food ration spatial differentiation is of special interest. In due time, the Soviet geographer A. Voyeikov paid attention to this fact. At various times scientists tried to "fix" and characterize the mentioned types. H. Kariel, for example, compiled a map of territorial localization of the geographic "nutrition types", selected by the basic sources of proteins [10].

At the base of analysis of the world population food ration spatial differentiation, carried out by us, there were laid the main groups of "nutrition pyramid": grain-crops (cereals), products of plant origin (except cereals, they are vegetables and fruit); products of animal origin.

Grain-crops are nutrition base of any civilization. Correspondently, our organism includes more than a half of substances contained in the grain–crops. Precisely to the components contained in grains, our organism has adopted during thousands of years, its digestive system in particular. It is not accidently that man began cultivating grains. Only grain-crops could guarantee communities for survival and health.

The high role of grain-crops in human nutrition and health is determined by high content of amino-acids complex, including indispensable ones, carbohydrates, proteins, vitamins, microelements and other valuable elements. At the same time, the grain-crops cannot replace the products of animal origin, because their proteins are deprived of some important amino-acids. Low caloric capacity of plant origin proteins specifies insufficient food nutrient density among people whose food ration is based on plant edibles. As a result, a stable negative correlation was formed (-0.65 paired correlation coefficient) between the share of grain-crops in population's food ration and food calorie capacity index (Fig. 2).

More than 200 kg of grains per capita are annually consumed in the countries of the North and Central Africa and most of Asian countries. At the same time in the developed countries of Europe, Northern America and Australia this figure does not exceed 100 kg.

Grain-crops include wheat, rice, maize, barley, rye, oats, sorghum and some local cultures. Their consumption is increasing from year to year (Fig. 2). Hence, out of all

grains variety the leading place take "the three breads of the mankind": wheat, rice and maize. Though, rice and maize can be called a "bread" rather conditionally taking into account their important food value.

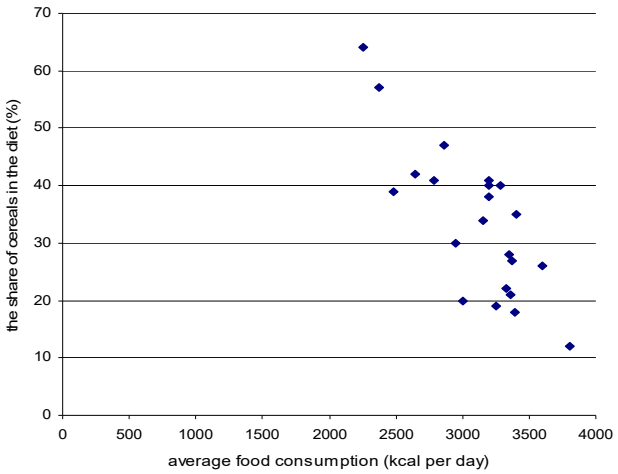

Fig. 2. Correlative interrelation of grain-crops shares in the world population food ration and average food consumption (compiled on FAO data, 2018).

As seen from Fig. 3-4, each of these cultures amounts nearly the third part of total grain-crops consumption in the world population food ration.

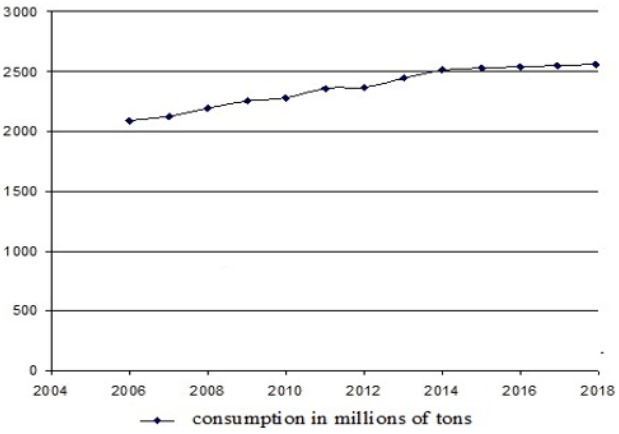

Fig. 3. The world grain-crops consumption.

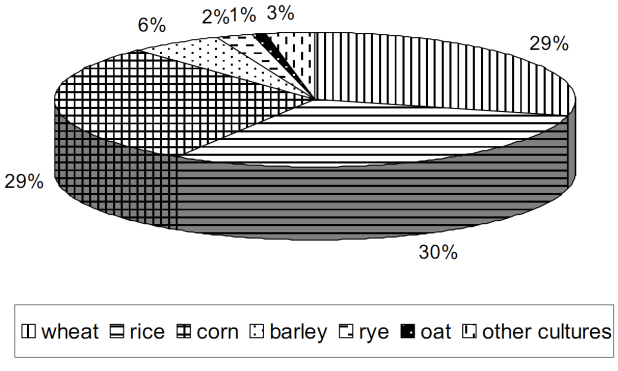

Fig. 4. Structure of grain-crops consumption in the world (right) – 2018 data.

Considering the domination of grain-crops in ration of major world nations, their correlation is put in the base of nutrition types classification, offered by H. Kariel. Hence, since the time of elaborating this classification the essential changes in the world population food ration have taken place, causing the need of illustrating its present-day status (Fig. 5).

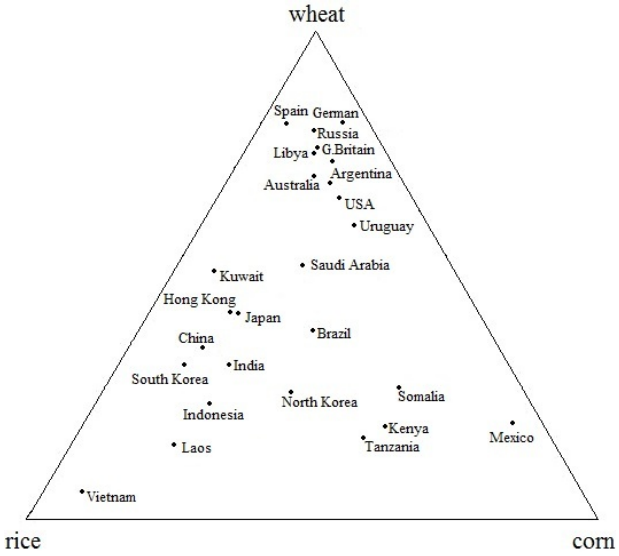

Fig. 5. Correlation of the main grain-crops in the world population food ration (compiled on FAO data, 2018).

As the diagram shows, wheat dominates in food ration in most European countries (Germany, Spain, Great Britain, Russia and others), as well as American ones (the USA, Canada, Argentina and others), and in the countries of different socio-economic types, and Australia too. Livia and Egypt make an exception. The specific rice ration prevails in Asian countries (Vietnam, Laos, Indonesia and others).

Maize is the basic nutrition component in Mexico and in number of South America countries (Guatemala, Honduras, Panama and others) and in East Africa (Somali, Tanzania, Kenia). The countries which have approximately the same ratio of the three types of grains – Brazil, Saudi Arabia, Japan, South Korea, Cuba and a number of others which are geographically dispersed.

So, the main geographic feature at present-day stage of grain-crops consumption is a change in the way of equalizing the role of each grains type in the world population food ration. The major reason for this is, evidently globalization and the imposed by it the tastes unification for population in the world different countries.

Fruit and vegetables are the most useful nutrients for human organism. Unlike animal nutrients and fish, vegetables almost completely do not contain fats. Really, neither root plants, nor green plant parts, practically contain oils and fatty acids. This allows including them into food ration practically at unlimited quantities.

The importance of these nutrients in the world population food ration varies within a large range: from 275 kg/person in Greece to 6 kg/person in Mozambique as to vegetables, and from 317 kg/person in Dominica to 1.3 kg/person in Eriteria as to fruit. The main reason for this gradation is nature-climatic conditions of the countries. The exception makes the economically developed countries that provide themselves with fruit

and vegetables owing to import. In spite of the positive dynamics of the world fruit and vegetables consumption (vegetables consumption rates growth amount approximately to 5% a year, and fruit 3% of that), in food ration of the grown-up population this index is practically as twice less as the minimum recommended by the WHO.

4 Results

The spatial analysis performed by us, revealed the following tendencies in indexes spatial differentiation of the world fruit and vegetables consumption:
- the most fruit (over 120 kg/person) are consumed in economically developed countries and in some other developing countries situated in tropical and sub-tropical belts (they are the main exporters of fruit and products of their processing);
- the least fruit (less than 35 kg/person) is consumed in African countries;
- by the volume of fruit consumption (over 145 kg/person) take the lead the countries of the Mediterranean and Eastern Asia;
- the least vegetables (less than 34 kg/person) are included in food ration by the population of Africa (except its northern part), South Asia and the northern part of South America.

As the Bennet's Law [21] states, in the course of a country's well-being growth its population begins replacing nutrients of plant origin for animal-originated food. This results in the substantial changes in habitual food ration of millions of people, which account replacement plant nutrients for food of animal origin. According to FAO statistics [23], since 1960 milk per capita consumption in the developing countries have increased by twice, meat – by three times and eggs – by five times. Correspondently, the world demand for these products substantially increased for the last fifty years. Moreover, by expert assessment, by the middle of the running century, the growth rates of the demand for protein nutrients will not only stop, but will essentially increase.

Food of animal origin is the food, which a human gets directly from animals or in the course of its further processing. Food of animal origin includes meat, fish, seafood, shrimps, crustaceans, milk, dairy produce, eggs, caviar. These products are a source of biologically important proteins, saturated fats, B group vitamins, fat-soluble vitamins, phosphorus as well as ferrous. Hence, by no means all the population on the Earth have a possibility to get all the vitally nutrients contained in foods of animal origin.

The maximum food of animal origin consumption (over 1100 kcal of daily ration) is marked in the countries of Europe, North America and Australia and the minimum (below 200 kcal of daily ration) – in Africa and_South-West Asia. This is one of the severe reasons of hunger in the countries of Asia and Africa. The meat content in food ration of population and the level of food consumption correlate positively at high (0.74) (Fig. 6). The very nutrients of animal origin can ensure the required norm of food consumption for the planet population.

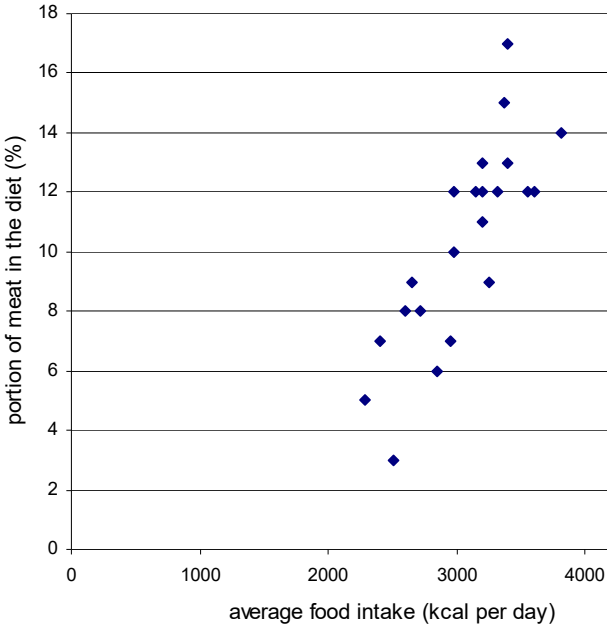

Fig. 6. Correlation of meat share in the world population food ration and the average food consumption (compiled on FAO data, 2018).

Analyzing spatial disproportions in food of animal origin consumption, we came up to the following conclusions:
- maximum meat consumption (over 80 kg/person a year) is found in the economically developed countries of Europe, North America and in Australia (except of Brazil and Mongolia), and minimum meat consumption (from 3 up to 10 kg/person a year) – in South and West Africa, and also in the major part of South-East Asia;
- milk and dairy produce dominate (more than 224 kg/person a year) in food ration of population in the USA, Australia and in the highly developed countries of Europe, at the same time, in the ration of inhabitants of Central Africa and South-East Asia they are practically absent (less than 15 kg/person a year);
- in food ration of the USA population, the most of countries of Europe and China the quantity of eggs exceeds 12 kg/person a year, and in Central Africa they are less than 1 kg/person a year.

So, in view of the dynamic processes in meat produce consumption which has been noted for the last 10 years, it is possible to say for sure that a large quantity of meat consumption per capita in the developed countries is quite typical during many years, therefore, the growth will be minimal. But in South-East Asia that has recently got economical possibility of purchasing meat protein nutrients, the amount of meat consumed will have increased by more than three times by 2050: from 3–10 kg/person a year to 30 kg/person a year. In this way, Asian countries are taking leadership by the rates of increasing demand for protein produce, in the first turn – for meat.

With regard to the fact that the world population food ration specificity forms the ratio of nutrients mentioned above three basic components of the "nutrition pyramid", we developed classification of nutrition types, which is grounded on quantitative indexes in grain-crops ration,

plant origin products (without taking into account grains) and food of animal origin (Fig. 2, 6). The classification takes into account not only basic structure of food ration, but its quantitative consumption as well.

For this purpose, statistics selection for each component was broken into groups on the principle of evenly tight intervals for three groups with minimal medium and maximum values. The marginal index values are shown in Table 1.

Table 1. The marginal index values of the basic structure components in the world's population food ration.

Groups	Grain-crops (kg/person)	Food of plant origin (kg/person)	Food of animal origin (kg/person)
Minimal	below 134	below 110	below 76
Medium	from 134 to 180	from 110 to 185	from 76 to 182
High	over 180	over 185	over 182

Map-making of spatial distribution of base components of the world's population food ration was carried out by the selected indexes. When overlapping cartographical layers (over-lineal operation), the typology of countries for their food consumption particulars through their distribution into groups (nutrition types) of basic components structure in food ration was made (Table 2, Fig. 7).

Table 2. The world's population food ration types classification by nutrition structure basic components.

Food ration types	Grain-crops	Food of plant origin	Food of animal origin
1	low	high	high
2	medium	high	high
3	medium, high	high	medium
4	low, medium	medium	high
5	medium, high	medium	medium
6	medium, high	medium	low
7	medium, high	low	medium
8	high	low	low
9	low, medium	low	low

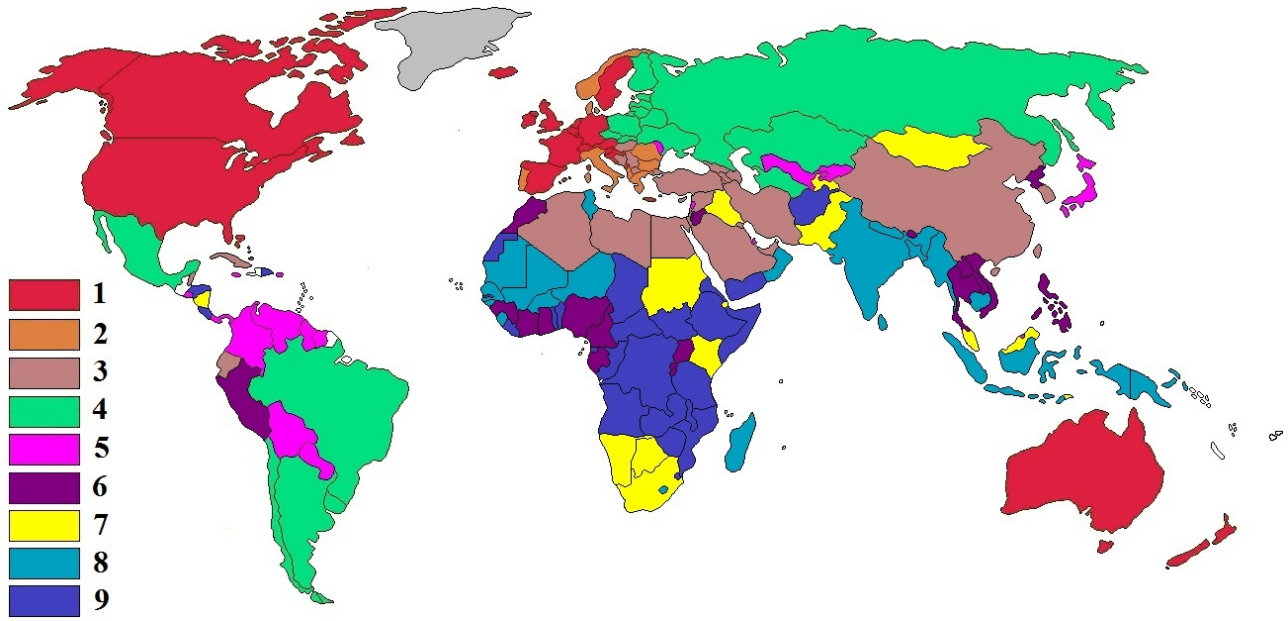

Fig. 7. Distribution of the world's population food ration types (according to classification shown in Tables 1, 2).

The world population food ration types brief characteristics in territorial groups will be given.

The first type includes the countries with unbalanced food situation. The majority of West Europe countries, the USA, Canada, New Zealand and Australia are among them. Common feature of these countries population food ration is a hypertrophied level of consumption by the number of calories (over 3400 kcal/person a day). It differs structurally by low norms of grain-crops consumption at rather high rates of plant and animal origin nutrients consumption. High level of fats consumption (over 30%) is a characteristic feature for countries of this type. This unbalanced nutrition causes spreading among the population of the said countries so-called "diseases of rich countries" such as cardiovascular diseases, obesity, etc.

Food ration of the second type is characterized by nutrition high balance at rather high level of food consumption (from 3200 to 3400 kcal /person a day). This is achieved for the account of using seafood for nutrition, because all these countries (Greece, Italy, Portugal, Albania and others) have access to the sea. Moreover, the role of grain-crops in ration increases, which is determined by cultural-historic development of these regions.

The countries of the third food ration type at this time have reached normal values (in FAO view) of daily ration caloric capacity – 2600 – 3100 kcal/person a day. This is

caused by some decrease of animal origin food content at high share of vegetables and fruit. Grain-crops are gaining in considerable importance. The countries with rather favorable food situation are referred to it. They are the countries of North Africa (Egypt, Livia, Algeria), the most developed Asian countries (Saudi Arabia, China, UAE, Turkey and others), and some European developing countries as well (Macedonia, Bosnia and Herzegovina and others).

The countries of the fourth food ration type are characterized by high consumption level values – the average daily ration caloric capacity amounts nearly 3100 kcal/person. They most the post-Soviet countries (Russia, Ukraine, Belorussia, Kazakhstan, Estonia and others), a number of European countries (Czech Republic, Slovakia, Finland), and the most developed Latin American states (Mexica, Argentina, Brazil, etc.). The majority of these countries solve the food problem at the account of their own resources. Nutrients of animal origin dominate in food ration at average values of grains, vegetables and fruit content.

Food ration of the fifth type is characterized by the most food consumption structure differentiation. It can be called as ration of "nutrition balance". At the average content of all basic components, the level of food consumption fluctuates within the range of 2500 – 3000 kcal/person a day. With the exception of Japan, they are the countries of lower level of economic development due to more limited resources for food import. They are mainly Latin American (Venezuela, Columbia, Paraguay and others) and Asian (Kyrgyzstan, Lebanon, Uzbekistan and others) developing countries.

Food ration of the sixth and seventh types is specified among the population with food situation at the stage, which is normalizing. Yet, some years ago, the problem of hunger was the most actual in these countries. The difference among them is connected mainly with a bigger share of animal nutrients in ration of the seventh type, which is compensated by stable-medium quantity content of vegetables and fruit in ration of the sixth type. In this regard the countries achieved acceptable values of ration caloric capacity (from 2100 to 2500 kcal/person a day). The sixth nutrition type includes mainly the countries of West Africa (Ghana, Nigeria, Côte d'Ivoire and others) and Indo-China peninsula (Vietnam, Laos, Thailand and others). The countries with food ration of the seventh type are territorially re-dispersed. It is to the south and east of Africa (SAR, Namibia, Botswana) and South and Central Asia as well (Mongolia, Pakistan, Malaya and others).

The countries with food ration of the eighth and ninth types are the ones suffering of food crisis. Daily ration caloric capacity values make up less than 2200 to 2500 kcal/person for the eighth type, and less than 2000 kcal/person a day correspondently. Higher food ration values of the eighth type are conditioned by compensation of the shortage of basic nutrition components for higher content of such grain-crops as wheat and rice. The ration base for population with the ninth nutrition type are millet-crops (sorghum, first of all) providing with 40% of calories and rood plants.

Food problem solving in these countries is not possible without involvement of international organizations. The group includes the majority of Central and East African countries and the number of South and South-East Asia states.

5 Conclusion

So, in the result of the complex geographic researches the world countries typology by food consumption characteristics through their division into groups (nutrition types) relating to food ration basic components was carried out. The proposed methodology of differentiating population food ration types can be considered as one of the instruments for monitoring the dynamic processes of providing the mankind with food nutrients and developing the ways of solving food problem in the world.

The authors consider further research of this problem in analyzing geography of physical food nutrients accessibility, which assumes studying the basic food produce availability for population in countries or regions in amount and assortment corresponding to the prescribed rational norms of consumption, needed for providing health and human active life.

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Lean production as a means of ensuring the sustainable development of agricultural enterprises

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Abstract. The article considers the theoretical essence of the lean production concept. It has been proved that its essence lies in identifying and reducing costs of processes, and sometimes eliminating business processes that do not create added value but consume large amount of resources. The main constituent elements, tools and principles of lean concept implementation have been outlined. The possibility of implementation of lean logistics in the activity of agricultural enterprises has been considered. It has been defined that combination of lean logistics and "green logistics" is a rational way to increase both economic and ecological efficiency. The VSM tool have been offered for implementation of the lean concept. VSM maps provide a visual representation of step-by-step scenario to achieve the strategic goals of the company, representing material and information flows required to deliver a product to the final consumer. It has been confirmed that the implementation of the lean concept at agricultural enterprises is an element of ensuring their functioning on the basis of sustainable development, a means of increasing environmental and economic efficiency.

1 Introduction

Exacerbation of crisis tendencies in the socio-economic sphere, increase of competition for resources, understanding of their exhaustiveness and the need for efficient and rational use, deterioration of the natural environment place particular emphasis on ensuring the sustainable development of the economy as a whole as well as of its individual industries.

Sustainable development as a concept of social and economic development involves balanced and stable functioning of economic entities with ensuring minimum of harmful impact on natural environment. Sustainable development contributes to the following:
- efficient functioning of the economic entities;
- balanced use of natural resources and reduce of the anthropogenic burden on natural environment:
- ensuring the society well-being through the supply of safe food products and providing normal living conditions.

Taking into account the mentioned above, sustainable development ensuring is extremely important under modern conditions.

Ensuring sustainable development is especially important for agricultural enterprises, as agricultural production not only shapes the food security of the country, but also acts as a direct user of natural resources. Therefore, management of the agricultural enterprises' activities on the basis of sustainable development is an important prerequisite for improving their ecological and economic efficiency. We believe that the solving of the mentioned task can be realized through the implementation of lean technology.

The lean production concept is based on the reduction of costs, which do not create value for consumer but make the final product more expensive. The relevance of the research is confirmed by the fact that in some countries about 20 % of agricultural products don't reach the final consumer, although their production consumes a considerable amount of resources (including natural) [1, p. 102]. This situation requires the implementation of effective mechanisms of agricultural producers' activity efficiency increase in order to ensure their functioning on the basis of sustainable development.

1.1 Literature review

The importance of researches in the sphere of lean production has caused significant interest of scientists to the issue mentioned.

One of the most comprehensive approaches to the study of lean production concept implementation is provided by J. Liker [5]. The peculiarities and insights of the Toyota company experience at the lean production implementation are considered providing a complex and precise view of how the lean concept should be introduced in the Ukrainian practices. Another research

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which should be mentioned specifically is performed by J. P. Womack and D. T. Jones [17]. The complex characteristics of the main foundations of lean thinking concept is provided by the authors as well as the recommendations for practical implementation of lean concept.

O. Kobyliuh, H. Melnyk [4] mention that currently the lean concept is wide-spread in many countries with high level of economic and industrial development. The authors generalize the theoretical basis of the lean concept as well as practical aspects of its implementation.

H. Shportko and M. Vyshnevska [16] define the theoretical aspects of value stream mapping (VSM) as of the one of the efficient lean concept tools. The researchers provide the characteristics of the methodology of VSM implementation and consider the benefits provided by the tool.

The peculiarities of lean production concept implementation in the activity of agricultural enterprises are considered in the researches of D. Folians, D. Aidonis, N. Voulgarakis, D. Triantafylou [8] and V. Vostriakova [1]. The articles define the possibilities of lean tools implementation in activity of agricultural enterprises and emphasizes the role of VSM tool in the optimization of logistic activity costs formation processes.

Another tool which is similar to lean production concept according to its goals is so-called "green logistics". The "green logistics" concept is considered in the researches of I. Smyrnov [6], Paul R. Murphy, Richard F. Poist, Charles D. Braunschweig [14] and O. Kostiuk, M. Kaniuka [15]. The authors' [6; 14] definition of "green logistics' concept provides for more comprehensive understanding of lean production concept as these tools are deeply related from the point of view of their ecological impact. In the research of O. Kostiuk and M. Kaniuka [15] the main directions of logistic activity improvement on the basis of its "greening" are defined. V. Cruz Machado and S. Duarte [12] consider "green logistics" as well as lean supply chin among the supply chain paradigms which empower the enterprises to be more efficient in the logistic activity.

Practical cases are a powerful tool of definition of the road-map of lean production concept implementation, that causes the appropriate scientists' interest to this sphere [2; 3; 9; 10; 11]. Lean production concept as a theoretical background for the further research is reviewed in the B. Poksinska and D. Swartling research [2]. The authors define the opportunities and benefits provided by the lean concept implementation as an improvement programme through the introduction of a practical case of biopharmaceutical company. Bhuvaneshwari Alias Sunita Kulkarni and Anand H. Mishrikoti [3] state that lean production concept implementation forms a great impact on the functioning of small and medium-sized enterprises as it ensures waste reduction and costs optimization. The authors study several cases of lean concept implementation in various spheres of economic activity defining the peculiarities and outcomes of such practices. The Brazilian agricultural enterprises' experience in lean tools implementation is considered in the research of E. G. Satolo et al. [10]. The research provides a description of the most common lean concept tools and techniques as well as a practical view of their implementation in the activity of Brazilian agricultural business units. M. Melin and H. Barth [11] provide an extensive view on peculiarities of lean concept implementation in Swedish agricultural sector. The authors outline the essential elements and phases of lean thinking implementation, as well as note the role of appropriate governmental support programmes.

Acknowledging the valuable and significant contribution of the researchers in the sphere of lean production we should mention that the further development of ideas of lean production concept implementation in the activity of agricultural enterprises is relevant.

1.2 Objective of research

The purpose of the research is the acquaintance with conceptual foundations of lean production and substantiation of the possibility and expediency of application of the basics of this philosophy in agricultural enterprises activity in the context of ensuring their sustainable development.

2 Results of the research

The need for radical changes in the activities of Ukrainian agricultural enterprises is due, first of all, to the low quality of production and its high cost. Therefore, solving of these issues lies in the sphere of improving the efficiency of all business processes, both primary and support. According to foreign experience, the technical re-equipment of production, in the opinion of most farmers, will not ensure the proper level of all business processes efficiency and will not increase the efficiency of the latter, because it does not take into account the issues of personnel management, organization of logistics flows, financial flows management and the enterprise management as a whole. Thus, mastering the principles of lean production can be a significant competitive advantage in the current stage of management. The lean concept implementation in the activity of agricultural enterprises is capable to provide benefits for the economic entity and the society both, as it enables waste reduction (ecological impact) and costs decrease (economic impact).

2.1 Lean production concept

The concept of lean production is based on the idea of the business model of the enterprise, namely its part, which studies the business processes of the enterprise: primary, support and service, in terms of their role in creating added value, which is determined by the consumer value. So, the essence of lean production provides the identification and reduction of process costs, and sometimes elimination of those business

processes that do not create added value but use a large amount of resources.

Lean concept is one of the most popular and efficient contemporary management tools as it provides not only increase of functioning efficiency, but also benefits to rational nature resources use.

The origin of lean concept comes from the case of Toyota company, particularly, the Toyota Production system, which was developed in the 1940s.

The lean production concept is defined as a system approach to production and other business processes organization, which involves continuous improvement, reduction of waste and satisfying the needs of consumers.

Lean production concept can be described both as a philosophy as well as a tool for production processes improvement [2].

Lean concept as a philosophy involves the formation of the consciousness of managers of different levels and directly employees of enterprises, which will be based on the principles of resource saving, rational resource use, waste reduction and recycling. Lean concept philosophy is focused on the continuous improvement and search of managerial and organizational approaches to the effective organization of business processes and the avoidance of unjustified losses and waste of resources.

In practical terms, lean concept includes a set of techniques and tools aimed at identifying "bottlenecks", reducing wastage and cost of resources in the implementation of various business processes.

Lean production concept tools and methods include a large number of techniques which can be applied in the economic entity activity. The most common tools of lean production concept include the following:

- 5S method – is aimed at reduction of waste of resources due to the improper organization;
- Kaizen – provides the opportunity to avoid waste in the production process;
- Kanban – benefits to avoiding wastage from overproduction and surpluses in stocks;
- Muda – is aimed at reduction of any activity and / or business processes which do not create added value for the product [3];
- Overall equipment effectiveness – ensures the flows tracking in order to avoid wastage in the production process;
- Value stream mapping – provides a graphical reflection of the production flow processes and enables identification of the "bottlenecks" of the process;
- Total productive maintenance – involves higher participation of employees in production and improvement processes that allows to avoid defects and decrease the duration of production cycle;
- Andon – provides the possibility for improving the communication during the production process, etc. [3].

The basis of "lean production" is called "muda". "Muda" means losses, unreasonable costs and any processes in the activity of the enterprise consuming resources without giving any value to the product or service [4, p. 45].

Main lean principles were defined by Jeffrey K. Liker on the basis of Toyota experience and include the following [5]:

1. Base Your Management Decisions on a Long-Term Philosophy, Even at the Expense of Short-Term Financial Goals.

Adherence to this principle determines the priority of the strategic goals of the enterprise development in relation to its short-term perspective. Thus, obtaining short-term benefits can lead to lost opportunities in the strategic perspective, and reduce the level of success and competitiveness of the enterprise in the future.

2. Create Continuous Process Flow to Bring Problems to the Surface [5].

The relevant principle defines the importance of a systematic and continuous approaches to the organization of business processes in order to identify and eliminate "bottlenecks".

3. Use Pull Systems to Avoid Overproduction [5].

Provides an orientation of production processes on consumers' demand and a clear alignment of production volumes with consumer demand. The implementation of this principle will help to avoid over-costs due to the formation of unreasonable inventories.

4. Level Out the Workload (Heijunka) [5].

Compliance with this principle implies ensuring that the equipment is "aligned" to avoid downtime and peak loads, or the so-called "smoothing" of production.

5. Build a Culture of Stopping to Fix Problems, to Get Quality Right the First Time [5].

It is one of the principles that is formed at the managerial level and provides for the possibility of stopping production processes in case of problems in order to ensure a high level of quality of final products and avoid losses.

6. Standardized Tasks Are the Foundation for Continuous Improvement and Employee Empowerment [5].

The defined principle is based on the premise that the unification and standardization of works contribute to improving the quality of their performance, simplifying the procedural component for employees, and therefore provide a basis for improving production processes.

7. Use Visual Control So No Problems Are Hidden [5].

Provides the formation of a system for monitoring the quality of products and the organization of business processes in terms of timely identification and appropriate elimination of problems.

8. Use Only Reliable, Thoroughly Tested Technology That Serves Your People and Processes [5].

Involves the application of only proven techniques and technologies in the process of organization of production and other business processes, which provides for their adjustment and avoidance of accidental unjustified losses.

9. Grow Leaders Who Thoroughly Understand the Work, Live the Philosophy, and Teach It to Others [5].

Adherence to this principle determines the role of leadership and qualification of managers of different levels, who are subordinated to the corporate spirit and

corporate culture, thus contributing to improving the efficiency of the enterprise.

10. Develop Exceptional People and Teams Who Follow Your Company's Philosophy [5].

This principle is in line with the previous one, because under the current conditions of increasing competition, it is human resources that are the source of the formation of significant competitive advantages. Forming a team of employees who will share the values of the organization is an important prerequisite for improving its efficiency.

11. Respect Your Extended Network of Partners and Suppliers by Challenging Them and Helping Them Improve [5].

The implementation of lean concept in the activity of the enterprise puts appropriate demands on its suppliers in terms of quality assurance of resources, timeliness of deliveries, etc. Forming long-term business relationships with reliable suppliers, sharing with them some of the best know-how and skills contributes to improving the quality of input resources.

12. Go and See for Yourself to Thoroughly Understand the Situation (Genchi Genbutsu) [5].

Provides the personal involvement of executives in the identification of problems, their resolution and improvement of processes.

13. Make Decisions Slowly by Consensus, Thoroughly Considering All Options; Implement Rapidly (Nemawashi) [5].

Adherence to this principle implies a comprehensive substantiation of management decisions, taking into account all possible alternatives and perspectives. At the same time, after a decision is made, it is advisable to implement it quickly, since the conditions and factors of both the external and internal environment are characterized by variability, which calls into question the efficiency of the implementation of a decision over a long period of time.

14. Become a Learning Organization Through Relentless Reflection (Hansei) and Continuous Improvement (Kaizen) [5].

Involves the necessity for continuous development and improvement of the organization in order to ensure its sustainable and competitive functioning.

According to the world experience, the implementation of lean production concept makes it possible to: reduce production costs; reduce order fulfillment cycle; reduce labor costs and labor losses; reduce stocks; increase production [6].

The essence of lean production is that all these types of costs are controlled by the company independently. If the price is dictated by the market through the consumer, then the rate of return will directly depend on the amount of costs incurred in production as the equation is the following:

$$Price = Costs + Profit \quad (1)$$

Therefore, the company should take maximum measures to minimize all types of costs keeping the same quality of products. Taking into account the mentioned above, the concept of lean production is based on the following principles:

- to produce only the amount of products needed on the market;
- to abandon mass production;
- to minimize work in progress (unfinished production);
- to minimize stocks.

In view of the above, one can ask the following question: is it possible to introduce the basic principles of lean production in the agricultural sector, the peculiarity of which, along with the seasonality of production (crop harvesting is mostly collected once a year), is its mass production? The answer is that current conditions are so that the consumer is not ready to pay for products that are stored for a long time, are processed for storage with chemicals, and thus lose their quality and value. The consumer requires organic products (the feature of which is the impossibility of long-term storage). Meeting the mentioned consumer's needs contributes to the reaching of the following sustainable development goals: "Zero hunger", "Good health and well-being" and "Responsible consumption and production" [7].

2.2 Lean production concept implementation cases

Practical cases demonstrate the feasibility of implementation of lean technology into agricultural enterprises' activity. Thus, Greece's experience in the production of compound feeds once again shows the whole chain of lean production in action. Instead of drying corn up to 14% with energy consumption of 0,15 kW / t, storing it in an elevator and ventilating with special devices, spending additional energy on it, compound feed plants are organized. On these plants, corn is added to other feeds at a specified percentage weight.

There the corn is weighed, crushed, pelleted and packed or transported to the farm free of packing. Thus, energy consumption for compound feeds production is 85 kW / t, water consumption in the form of steam is 40-60 kg / t. Emissions are limited by gas / oil emissions when the water is heated to the steam state, solid waste in the form of dust is filtered into special bags, liquid emissions are absent [1; 8; 9].

Another successful case of lean principles implementation can be observed at the example of Brazilian agricultural enterprises. Thus, Satolo Eduardo Guilherme et al. state that Brazilian agricultural enterprises (at the example of eight research units) utilize a number of lean production tools and techniques, among which are the following: autonomation, continuous flow, pull production, standardized work, kaizen, supply chain integration, uniform work load, total quality management, etc. [10]. The implementation of the tools mentioned above allows the research units to operate successfully, satisfying consumers' needs with simultaneous reduce of production costs.

The role and efficiency of lean concept implementation is also substantiated by some governmental programs. Thus, in 2010 the "Lean

agriculture" governmental program was introduced in Sweden. The program provided learning of lean principles for agricultural producers, including traineeship, workshops and coaching in order to achieve the increase in performance efficiency. Approximately 100 farms have been involved to various types of activity within the program since it was introduced [11].

Thus, foreign experience in lean production concept implementation reflects its efficiency and effectiveness as well as forms the road-map for Ukrainian enterprises which are willing to apply the lean principles.

2.3 Lean logistics

Understanding the essence of the lean production concept makes it possible to implement it, if not for the whole process of agricultural production, then at least for such an important direction as lean logistics. Supply chain management will increase the efficiency of the production process as a whole. It should be noted that lean logistics should not be equated with "green supply chains". The latter focus on environmental protection through the maximum use or recycling (elimination) of waste. Lean logistics focuses on reducing costs and meeting consumer requests, while increasing the efficiency of agricultural production by increase of value added.

The implementation of lean logistics aims at optimizing the processes of the entire supply chain in order to simplify it, reduce losses and processes, which do not create value [12]. In other words, optimization of processes and acceleration of their execution will reduce the costs and increase the efficiency of the production system. The authors' lean concept in the agricultural supply chain is presented in Fig. 1.

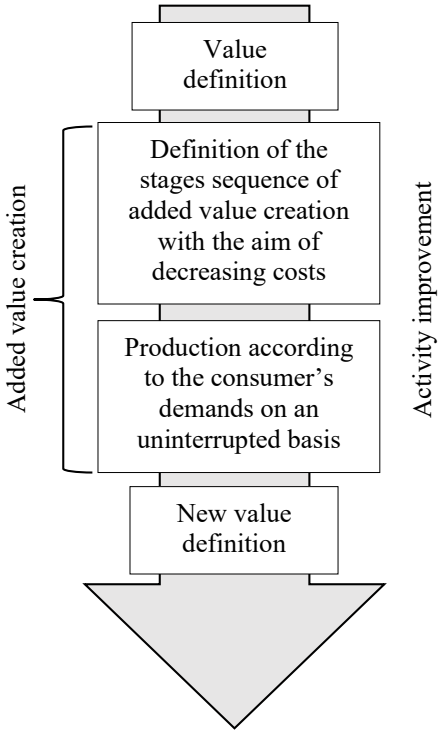

Fig. 1. Lean concept in the agricultural supply chain.

One of the Ukrainian agricultural enterprises that has introduced best practices with the use of lean tools such as the "5S" and the proposals of the employees for improvement of their work is the "Agro-Soyuz" holding. The results were a number of the following measures: the initiation by employees of 54 measures to balance the flow, 45 of which do not require investment; saving of 37 ths. UAH due to the systematization and redistribution of the furniture between the corporation divisions in the course of implementation of the principle "Removal of unnecessary"; receiving significant funds from scrap sales; a 41% increase in productivity [13].

"Green logistics", along with the concept of lean production, is important in agricultural production. According to P. Murphy, the term "green logistics" originated in the early 90's of the XX century as a new method in logistics, which guides standard logistic requirements to the rationality, efficiency and speed of processing and movement of goods, and takes into account environmental measures [14]. "Green logistics" is understood as a tool for maintaining environmental security, which is an example of a socially beneficial and business-friendly symbiosis of ecology and economy and satisfies the terms of both preserving the natural environment and economic activity growth [6, p. 50].

Lean production in the context of the lean concept is a part of a large chain of "green logistics" that integrates financial, logistical and information flows while reducing costs throughout the value chain. Lean production provides the opportunity to gain a sustainable competitive advantage in the market by reducing material, energy, storing and transportation costs.

Among the global companies that adhere to the principles of "green logistics" are Toyota, Xerox, Johnson & Johnson, Honda, Volkswagen, Hewlett-Packard, Casio, Sony and others. The effectiveness of "green logistics" principles can be demonstrated in practice by Sony, which in 2011 managed to reduce CO2 emissions by approximately 47% due to the packaging reduce. In 2011 also, Sony used about 31,000 return containers worldwide, thereby reducing the use of packaging materials and single-sided pallets by approximately 312 tones [15].

Due to the change in the thickness of the stretch film, its use decreased in volumes of up to two tons, which in turn contributed to the reduction of CO2 emissions by approximately five tons [15].

V. Vostriakova believes that the integration of lean and "green" logistics can create a hybrid agricultural and food supply chain that, along with cost reductions, will reduce environmental footprint and increase business efficiency and, as a consequence, product quality [1].

Under current conditions, this issue is relevant because, firstly, transportation does not add value to the product from the point of view of the final consumer, that is, it becomes a cost for the enterprise and, secondly, among many logistics systems (supply logistics, information logistics, sales logistics, production logistics, transport logistics) transport logistics is the most damaging to the natural environment.

With its abundant natural resources, Ukraine is one of the most polluted countries in the region. According

to the environmental index, which is derived from 10 indicators, among which are water and air condition, biological diversity, environmental diseases, Ukraine ranked 102nd out of 132 countries [15].

The leading postulate of the lean concept, as noted, is that there are two types of costs: the first – the ones that create value for the consumer, all the others – bring only losses.

2.4 Application of Value Stream Map tool

Therefore, there are two types of costs in any production: costs that can either be reduced or avoided (overproduction, surpluses stocks, defects elimination, irrational internal logistics, unnecessary operations, downtime and equipment overhaul), and non-avoidable, and they do not create value for the consumer (labor costs).

The success of the lean concept in agricultural production can be ensured by the breakdown of the entire production process into a chain of operations, which create value added and which only generate costs. This can be done using the VSM (Value Stream Map) tool.

VSM is a visual representation of a step-by-step scenario for achieving the strategic goals of the enterprise; is a graphical diagram which shows the material and information flows required to deliver a product to the final consumer. The map allows to identify the "bottlenecks" of the flow, existing losses and develop a plan for costs optimization. This map gives the opportunity to:

- distinguish valuable and invaluable processes and determine what is most important to the consumer;
- reduce losses which are not paid for by the consumer;
- produce a map of the movement of products and information to the final consumer;
- model the process as a whole but not its individual parts [16].

Thus, it can be assumed that due to the VSM tool, the company will be able to analyze the entire production process, determine the stage at which value is added, and optimize costs that do not create value for the consumer, but increase the cost of the process. This tool helps to visualize agricultural business processes, from raw material delivery to final product, with key milestones, resources needed and time for implementation.

Designing a value stream map is one of the most important tools for building an organization in accordance with the principles of the lean production philosophy. Fig. 2 shows that this process is divided into two main stages of creating a VSM map.

Therefore, in the general form for agricultural enterprises the VSM card should have the following: defining a business process that creates value added and setting the time for its implementation; calculation of the required amount of energy resources (water, electricity, gas, oil, etc.) spent on production of a certain products volume; considering that the business process can be primary, support, service and managerial, the amount of energy resources is calculated to ensure the execution of each process per day; identifying processes that have the potential to increase resource efficiency and reduce costs, reduce environmental footprint, ensure the safety of the natural environment and the entire chain.

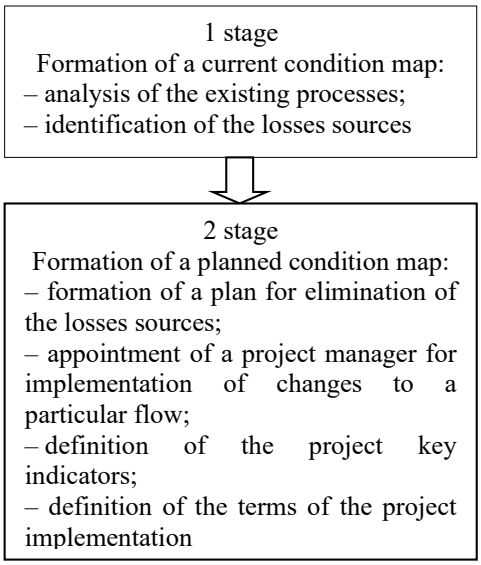

Fig. 2. Stages of VSM formation.

The implementation of lean production principles will allow agricultural enterprises to find out cost-cutting reserves through optimization throughout the agricultural-food chain, to identify processes that do not create added value, but only burden the production process with unproductive costs. Thus, according to M. Porter, the company will gain a competitive advantage by minimizing costs. This, in turn, will increase competitive position in the market, because the company will present its product in the form of value, not burdened with other costs. At the same time, the implementation of lean concept will help to reduce the anthropogenic burden on natural environment and to achieve the sustainable development goals.

Therefore, it can be confirmed that the implementation of the lean concept at agricultural enterprises is an element of ensuring their functioning on the basis of sustainable development, a means of improving environmental and economic efficiency.

3 Conclusions

Considering the environmental orientation that has developed in the global community at the present time, it is important for Ukrainian agricultural enterprises to combine the lean concept with "green logistics", which combine rational use of resources and environmental protection. Therefore, theoretical and practical aspects of finding of the intersection of points of interests and the possibilities of combining these two concepts require further development, in the context of the mechanism of implementation and expansion of tools for their application in our country. Lean production is the key to the sustainable development of agricultural enterprises.

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Economic security and innovation activity of personnel – determinants of sustainable development of enterprises

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Abstract. The article substantiates that achievement of certain economic security level set by management for the current time point is a necessary but insufficient condition of further development of the enterprise. When the mentioned condition is fulfilled, the degree of its personnel's innovation activity should also be considered. The article presents further development of the methods of assessing the level of the dependent part of economic security of the enterprise's stakeholders, including the personnel, which, unlike others available, is based on estimation of outstanding expenditures. Innovation activity of the personnel is determined to depend on their attitudes to innovations. The article presents a developed economic and statistic toolkit of assessing the personnel's probable attitudes to implementation of innovations considering the degree of recognizing the necessity of innovations and awareness of the enterprise's activities in terms of innovations. The level of probable (expected) attitudes to innovations is taken as a basis for a combined classification of particular personnel categories. The article suggests a matrix approach to determining the type of enterprise development based on comparison of the level of economic security for the current time point and the personnel's innovation activity.

1 Introduction

1.1 Problem statement and its topicality substantiation

During its functioning, any enterprise goes through several stages of development. However, even on achieving the best results in its economic activities, it cannot always maintain this state. This is, first of all, caused by the volatile nature of the external environment. The competitive environment stimulates activities of the enterprise which aim at further functioning and which are of interest for owners. Sustainable development is based on certain factors, its economic security and innovation activity of its personnel being the most significant among them under current economic conditions. In case of danger, key tasks of the enterprise shift towards survival and stabilization of its performance. Due to that, sustainable development plays a smaller part. Yet, for further development, the enterprise should leave its comfort zone – the zone of its economic security. However, in any case, possibility of development is provided at the expense of innovation activities of its personnel. At the same time, economic processes in Ukraine do not allow national enterprises to ensure transition to intensive performance forms. One of the reasons for this is poor efficiency of innovation activities, insufficient involvement of personnel into innovative processes.

Foreign practices of innovation management enable asserting that qualitative use of personnel's innovation potential and formation of their high innovation activity are crucial factors of increasing innovation activity efficiency at any enterprise under conditions of current economic development. Thus, one can assert that it is the level and dynamism of personnel's innovation development, the degree of use of their innovation potential under current economic conditions that ensure sustainable economic development and competitiveness of enterprises.

No doubt, implementation of innovations is very important but personnel's attitude to them may be different – from active recognition, approval and desire to implement to active aversion and resistance to implementation. The latter may be caused by many factors, poor awareness of necessity, reasons and peculiarities of the enterprise innovation activity being one of them. Considering the above mentioned, the issue of enhancement of methodological approaches to assessing probable attitudes of personnel to innovation implementation, development of corresponding economic and statistic tools is gaining topicality.

Thus, assessment of qualitative use of personnel's innovation potential and economic security as modern determinants of sustainable development of an enterprise require enhancement.

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1.2 Analysis of the latest researches and publications

In current literature, many scientific works deal with assessment and management of innovation potential of an enterprise. Issues of this type of assessment are considered in number of works, however, considering assessment of enterprise innovation potential as a whole, scholars do not pay sufficient attention to assessment of innovation potential and activity of enterprise personnel. In particular, the authors of [1, 2] present indicators of assessment of personnel's innovation potential at an enterprise, while the works [3-8] consider some of the relevant methods.

Quality characteristics of employees' innovation potential and their attitudes to innovations are dealt with in [9-12]. Importance of this kind of assessment is stated but corresponding analytical tools are not indicated.

Availability and conditions of the innovation potential of enterprises' and organizations' personnel impact the Global Innovation Index which dropped from the 43rd place in 2018 to the 47th place in 2019 [13-15]. An entire section is devoted to human capital as a component of the above index. The main indicators in the section are the following: education is on the 43rd place in the world, higher education and research and developments take the 37th and 54th places respectively (2019) [15].

Review of recent researches and publications demonstrate that personnel's innovation potential use is not sufficiently covered, and economic and statistic assessment of probable personnel's attitudes to innovation implementation is not almost considered.

We believe that all existing indicators and methods of assessing personnel's innovation potential including those describing personnel's attitudes to innovations, their innovation activity have the right to exist. In the innovation theory there are no strict requirements, criteria or rules demanding application of certain techniques of assessing innovation activity of an enterprise or its innovation potential and, therefore, managers select approaches to this assessment considering various conditions of enterprise performance.

According to the scholars dealing with assessment of personnel's innovation potential and national practitioners, the methods of point assessment, expert assessment, the index method, the method of relatives considering levels of significance, correlation analysis, methods of qualimetric assessment and others are the most widely used. Variety of methods of analyzing enterprise personnel's innovation potential is caused by complexity of consideration and quantitative assessment of factors impacting the level of personnel's innovation potential. Besides, application of the methods of expert and point assessment introduce certain subjectivity into the analysis. Due to this, we find it reasonable to apply a mixed approach to assessment of personnel's innovation potential at the enterprise combining qualitative and quantitative indicators and tools. Thus, in our opinion, when assessing personnel's attitudes to innovations, the degree of their awareness of innovative processes at the enterprise, it is reasonable to apply point assessment. Economic and mathematical analysis is relevant for quantitative characteristic of the degree of their behavior inertia when implementing innovations.

Besides, there are many various approaches to assessment of the economic security level. From our point of view, the most appropriate ones in practical terms are those based on determining values of deficit of net and operating income as well as the short-received EBITDA value [16, p.12–14]. The authors of [17, p.23-25] consider the functional dimension of modern threats to sustainable development. Methods suggested in those works enable assessment of the level of enterprise economic security but they do not consider the level of security of stakeholders, enterprise personnel being among them.

2 Results

As a complement to the modern idea of enterprise performance, we find it reasonable to compare it with an operating complex mechanism driven by the engine but only if there is enough fuel for its performance. It is obvious that the performance duration, the covered distance and/or the number of movements depend on the amount of fuel. Such analogy enables better understanding of modern determinants of sustainable development of any enterprise. Personnel's innovation activity is one of the determinants. This very engine enables the enterprise to move, i.e. develop in the required direction. But a mechanism needs fuel to function. We believe that enterprise economic security is the fuel as it is the foundation underlying the kind of activities that aims at sustainable development. Moreover, certain types of fuel ensure greater engine power. Within the framework of the present research, this means that personnel of an economically secure enterprise focus more efforts on innovation activity aimed at sustainable development of the enterprise. Commonly, part of this activity is devoted to overcoming the unsecure state.

Personnel's innovation potential is treated as a component of that of the enterprise and means the ability of personnel to use the totality of their own innovation capabilities of active production, comprehension and implementation of innovations in their activities and the enterprise performance in order to reach the set goals and receive positive effects.

The level of using personnel's innovation potential depends directly on the degree of their recognizing the necessity of innovations and their awareness of planned innovative processes at the enterprise as this is what influences efficiency of new developments in future.

Degrees of personnel's recognition of the necessity of innovations and awareness of their development and implementation at the enterprise should be assessed through quick tests and statistic observations during surveys. The main task of such assessment is to determine the personnel's opinion on whether innovations are an important and preferential direction of the enterprise development, and whether they are aware of measures for development, implementation and use of innovations at the enterprise.

Answers to these questions enable working out the integral coefficient of personnel's probable (expected)

attitudes to implementation of innovations:

$$K_S = K_V K_O, \quad (1)$$

where K_V is the coefficient describing the degree of recognizing the necessity of innovations by personnel;

K_O is the coefficient describing the degree of personnel's awareness of planned innovative processes at the enterprise.

In terms of mathematics, we suggest determining the coefficients K_V and K_O as average values of the results of interviewing the personnel and by the 10-point scale according to the criteria matrix (Table 1).

Table 1. The matrix of the criteria of probable (expected) attitudes of enterprise personnel to innovation implementation.

Degree of awareness (K_O) / Degree of necessity recognition (K_V)	Aware	Unaware
Recognize	Obvious activity $6 \le K_V \le 10$; $6 \le K_O \le 10$	Potential activity $6 \le K_V \le 10$; $1 \le K_O \le 5$
Do not recognize	Obvious inactivity $1 \le K_V \le 5$; $6 \le K_O \le 10$	Potential inactivity $1 \le K_V \le 5$; $1 \le K_O \le 5$

So, the value of the obtained integral coefficient may vary from 1 to 100.

Considering the criteria of assessment of the coefficients K_V and K_O given in Table 1, the scale of criterion assessment of the integral coefficient of probable (expected) attitudes of personnel to innovation implementation is determined. The scale can be presented in the following way:

1-25 points is a low level of K_S. Personnel is potentially expected to be inactive in innovation implementation. Besides, this criterion mediately describes inactivity of owners and managers of the enterprise, or testifies to the incorrectly developed innovation strategy (personnel is unaware of innovation implementation). To increase the level of K_S, the enterprise management should:

1) revise or develop a new innovation strategy to increase personnel's activity and motivation in implementing innovations. The strategy should be consistent, understandable for realizers and have clear results (to recognize innovations, personnel should understand: what to do, in which succession, expected results, expected benefits (additional income));
2) develop a complex of measures for training, psychological training, development of personnel's creativity in the field of innovation activities;
3) develop a system of stimulating personnel's innovation activities.

26-50 points is an average level of K_S. Personnel activity is expected to be insufficient as they are unaware (badly aware) of innovation implementation or do not recognize (recognize insufficiently) the innovation necessity for the enterprise. At this stage, to increase the level of K_I the following should be done:

1) to ensure personnel's awareness of innovation implementation through revision and enhancement of the innovation strategy, policy and current innovation plans in terms of their purposefulness as regards final results, openness and understandability;
2) to carry out necessary psychological training, explanatory work concerning the necessity of innovation implementation and enhance quality of teaching innovation activities to personnel in order to increase the degree of innovation recognition;
3) to enhance the current system of stimulating personnel's innovation activities.

51-100 points is a high level of K_S. Employees are expected to implement innovations actively. Enterprise management should apply an effective system of incentives to incentivize employees who are active in implementing innovations, ensure a reasonable innovative strategy, policy and current plans enabling use of personnel's innovation potential fully.

Assessment of probable personnel's attitudes to innovations underlies research into the degree of inertia of their behavior within innovations activities. It should be noted that not all employees in groups with obvious or potential activity can exercise real activity in implementing innovations. This is caused by both subjective – individual characteristics of each employee (e.g. an insufficient professional and educational level, low ability of creative thinking, lack of experience and skills in their professional sphere, etc.) and objective factors (e.g. lack of innovation policies and planning, the unfavourable climate in the team for production of innovations, inefficient management, etc.). So, the degree of inertia of personnel's behavior can be determined on the basis of objective and subjective reasons and the matrix of their probable attitudes to innovations.

We suggest analyzing the degree of personnel's behavior inertia when implementing innovations by the matrix method (Table 2).

Table 2. The matrix of assessment of personnel's behavior inertia when implementing innovations.

Degree of activity (K_A) / Attitudes to innovations (K_P)	Activity	Inertia
Acceptance	Active acceptance $7 \le K_A \le 10$; $7 \le K_P \le 10$	Inertial acceptance $1 \le K_A \le 4$; $7 \le K_P \le 10$
	Indifference: $5 \le K_A \le 6$; $5 \le K_P \le 6$	
Resistance	Active resistance $7 \le K_A \le 10$; $1 \le K_P \le 4$	Inertial resistance $1 \le K_A \le 4$; $1 \le K_P \le 4$

Each quadrant of the matrix built on the integral coefficient enables describing a personnel group on the grounds of their behavior activity/inertia during implementation of innovations.

The integral coefficient of personnel's behavior activity/inertia is determined as follows:

$$K_I = K_A K_P, \quad (2)$$

where K_A is the coefficient describing the degree of personnel's activity when implementing innovations;

K_P is the coefficient describing the degree of personnel's attitudes to innovations.

In terms of mathematics, we suggest determining the coefficients K_A and K_P as average values of the results of interviewing the personnel (a certain group of employees). The questionnaire must contain several questions for each group ("activity – inertia" and "acceptance – resistance") to provide accuracy of determining the four states of employee's behavior when implementing innovations.

So, we suggest the system of assessing employee's behavior when implementing innovations at the enterprise. For instance, results of the survey on the degree of personnel's activity in respect of innovation implementation enable determining the following behavioral states: "strong activity" – 9-10 points; "moderate activity" – 7-8 points; "strong inertia" – 1-2 points; "moderate inertia" – 3-4 points. In terms of personnel's attitudes to innovations, the following behavioral states can be singled out: "accept completely, will not resist" – 9-10 points, "accept partially, will not resist" – 7-8 points, "accept partially, will resist" – 3-4 points; "do not accept, will resist" – 1-2 points. The 5-6 point result indicates personnel's indifference towards innovations.

The quadrant "Active acceptance" describes a group of employees-innovators who have a strong desire to participate in innovative processes, produce, implement and use innovations.

The quadrant "Inertial acceptance" describes a group of employees who are fast in accepting innovations. They can participate in production, implementation and use of innovations after additional discussions, explanatory work, some consideration, under influence of other employees or being incentivized.

The quadrant "Inertial resistance" describes a group of employees with slow acceptance of innovations. They are reluctant to participate in innovative processes and skeptical of innovative changes. Their attitude to innovations is implicitly negative. However, strong or weak inertia of such employees, so called "drift", allows including them into innovation implementation under influence of majority of employees, through orders and directives of administration or through gradual persuasion.

The quadrant "Active resistance" describes a group of conservative employees who are strongly against any changes and their attitude to innovations is clearly negative. Employees of this kind are hard to be convinced or incentivized. If necessary and to save time, they can be forced into innovative processes. However, this group of employees hinders sustainable development of their enterprise. Considering the fact that all the employees of the enterprise participate in the innovative process to this or that degree, it is important to work with this group of conservative employees gradually and steadily to avoid resistance for their part to innovation implementation.

The quadrant "Indifference" describes a group of employees who have not found their position yet, know little about innovations at their enterprise or have not been engaged into innovative processes before and, therefore, do not have their own opinion of this issue. It is a sound idea for managers in the field of innovation activities to incentivize this group of personnel. Whether the employees will join innovators or remain conservative depends on the managers' work.

General attitude of the enterprise to innovations, the degree of personnel's resistance to their implementation, the rate of implementation depend on which group is the largest. Considering the above, it is important to investigate the measure of association between the factors: the degree of understanding the necessity of innovations and the degree of personnel's awareness; personnel's activity and their attitudes to innovations.

Calculation of the rank correlation coefficient is the easiest way of determining the measure of association between the factors. Spearman's rank correlation coefficient is the most common:

$$\rho = 1 - 6\frac{\sum_{i=0}^{n} d_j^2}{n(n^2-1)}, \quad (3)$$

where d_j is deviation of ranks of the factorial feature and the final result; n is the number of ranks.

Let us assess the measure of association through the example of operating Ukrainian enterprises between:

a) the degree of personnel's awareness of innovation implementation at the enterprise and the degree of their recognition of the necessity of innovation implementation (Table 3);

b) personnel's attitudes to innovations and the degree of their activity (Table 4).

According to the data from Table 3, Spearman's rank correlation coefficient makes: 1-(6*4)/(6*(36-1))=0.89.

The rank correlation coefficient value indicates availability of the direct and rather significant association between the mentioned parameters of personnel's probable (expected) attitudes to innovation implementation.

The critical value of the rank correlation coefficient for $\alpha = 0.05$ and $n = 6$ will make $\rho_{0.95}(4) = 0.89$ that is less than the actual value of ρ. Thus, essentiality of the association is proved with probability 0.95.

According to the data from Table 4, Spearman's rank correlation coefficient makes: 1-(6*6)/(6*(36-1))=0.83.

The value of Spearman's rank correlation coefficient indicates availability of the direct and significant association between personnel's attitudes to innovations and the degree of their activity. The critical value of the rank correlation coefficient for $\alpha = 0.05$ and $n = 6$ will make $\rho_{0.95}(6) = 0.83$ that equals the actual value of ρ. Thus, significance of the association is proved with probability 0.95.

Summarizing the above, one can conclude that it is necessary to develop personnel's innovation potential to provide sustainable development of the enterprise. This process can be ensured through:

1) enhancement of personnel's attitudes to implementation of innovations;
2) optimization of personnel's behavior activity/inertia when implementing innovations.

The performed analysis demonstrates that the first parameter depends on two interdependent factors – the degree of personnel's awareness of innovation activities and their recognition of the necessity of innovations. The second parameter depends on the degree of personnel activity and their attitudes to innovations.

Table 3. Intermediate calculations of determining the measure of association between the degree of personnel's awareness of innovation implementation at the enterprise and the degree of their recognition of the necessity of innovation implementation.

Enterprise	Average degree of personnel's awareness (K_O)	Average degree of recognition of necessity of innovations (K_V)	Rank of indicator K_O (P_O)	Rank of indicator K_V (P_V)	Deviation of ranks (d_j)	d_j^2
"A"	7.1	7.4	4	5	1	1
"B"	7.7	7.5	6	6	0	0
"C"	7.6	7.3	5	4	-1	1
"D"	6.6	7.1	2	3	1	1
"E"	6.7	7.0	3	2	-1	1
"F"	6.2	6.3	1	1	0	0
Total	averaged 7.0	averaged 7.2				4

Table 4. Intermediate calculations of determining the measure of association between personnel's attitudes to innovations and the degree of their activity.

Enterprise	Degree of personnel's behavior activity/inertia when implementing innovations by criterion		Rank of indicator		Deviation of ranks (d_j)	d_j^2
	"acceptance-resistance" (K_P)	"activity-inertia" (K_A)	K_P (P_P)	K_A (P_A)		
"A"	7.2	5.9	5	4	1	1
"B"	7.6	6.1	6	5	-1	1
"C"	7.0	5.5	3	3	0	0
"D"	6.5	5.1	2	2	0	0
"E"	7.4	6.5	4	6	2	4
"F"	6.3	4.0	1	1	0	0
Total	averaged 7.0	averaged 5.5				6

Personnel is known to be part of enterprise stakeholders, namely internal ones. In our opinion, part of security of stakeholders (including internal ones) is a component of enterprise economic security. Particularly, security of any group of stakeholders includes the part that depends on the enterprise performance (internal economic security of stakeholders) and the part that does not depend on it (external economic security of stakeholders). At that, general economic security of internal stakeholders and owners depend on this enterprise to the greater extent than security of other groups of stakeholders. Assessment of the economic security level of an enterprise ($L(EcS')$) is integral and depends on the level of economic security of an enterprise as itself – without stakeholders ($L(EcSe')$), internal (dependent) economic security of stakeholders of the enterprise ($L(IEcSs)$) and external (independent) economic security of stakeholders ($L(EEcSs)$):

$$LEcS' = f(L(EcSe'); L(IEcSs); L(EEcSs)). \quad (4)$$

It is quite obvious that to provide its own economic security, the enterprise must at the same time provide security of economic interests of its stakeholders, including its personnel, by effecting certain payments. However, in some cases, the value of actual payments (Pa) to serve the stakeholders' interests may be less than their compulsory payments (Pc). Then the concept of outstanding expenses (EO) emerges:

$$EO = Pc - Pa, \quad (5)$$

$$EO \rightarrow min. \quad (6)$$

In view of the above, we suggest assessing internal security of enterprise stakeholders, whose interests are served due to performance of their enterprise (dependent security of internal stakeholders as well as the enterprise owners) through the value of outstanding expenses. At that, the outstanding expenses may be both current unpaid spendings and the amount of outstanding investments. The latter are characterized by the depreciation value and percentage of payments. It should be noted that one part of payments for serving the stakeholders' economic interests decreases the value of earnings before tax and the other part is not considered. The first group of expenses comprises wages and other social payments to personnel; the other group is exemplified by dividends. The above mentioned enables enhanced classification of outstanding expenses of the enterprise (Fig. 1).

To assess the part of personnel's economic security which depends on the enterprise, we suggest determining the amount of outstanding expenses by each category (in the simplified form – employees and top-managers). Similarly, we suggest assessing the amount of outstanding expenses by other groups of stakeholders whose interests depend on the enterprise as well as owners of the enterprise. We consider the latter separately from other internal stakeholders as their economic interests may be connected with not only this enterprise but also with other enterprises. Besides, the dependent part of stakeholders' security includes environmental security maintenance of which is financed by enterprises not for the sake of profits but for satisfying the stakeholders' interests – first of all, the community within whose residence area the enterprise functions.

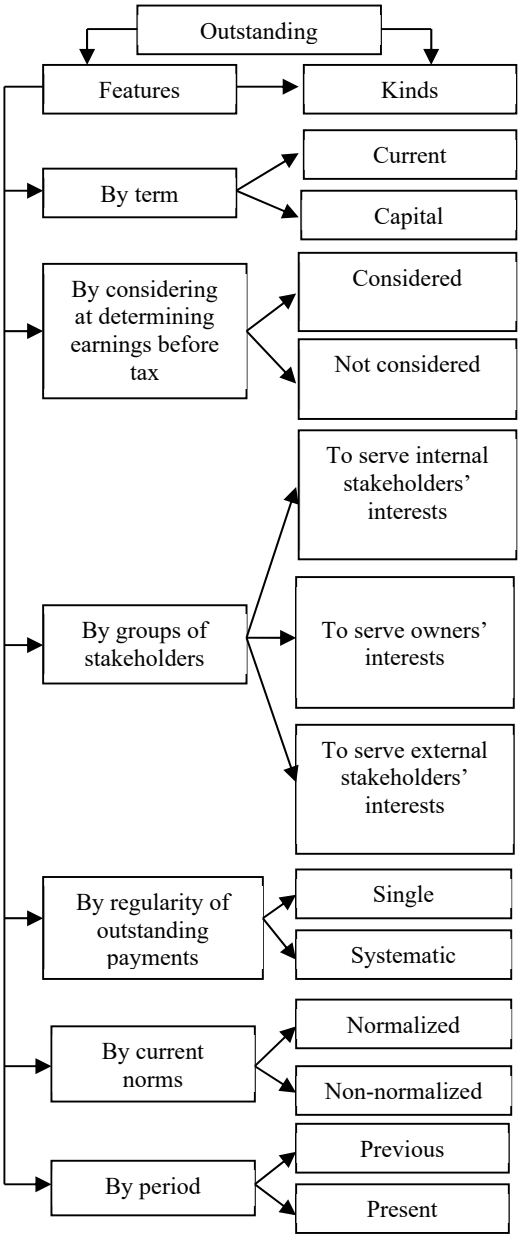

Fig. 1. Classification of outstanding expenses.

Thus, we suggest calculating the level of the dependent part of economic security of internal stakeholders whose interests are associated with the enterprise and of the enterprise owners and the area community ($L(IEcSs)$ according to the formula:

$$L(IEcSs) = 1 - \frac{EO}{Pa}, \quad (7)$$

where EO is the amount of outstanding expenses, USD;

Pa is the actual amount of payments effected to serve economic interests of internal stakeholders, owners and the community, USD.

The obtained data should be compared with the suggested scale:

- at $L(IEcSs) < 0$ – danger;
- at $0 \le L(IEcSs) < 0.25$ – the minimal level of the dependent part of internal stakeholders', owners' and the area community's security;
- at $0.25 \le L(IEcSs) < 0.5$ – the low level of the dependent part of internal stakeholders', owners' and the area community's security;
- at $0.5 \le L(IEcSs) < 0.75$ – the average level of the dependent part of internal stakeholders', owners' and the area community's security;
- at $0.75 \le L(IEcSs) \le 1.0$ – the high level of the dependent part of internal stakeholders', owners' and the area community's security.

Considering the approach suggested in [9], to assess the level of economic security of the enterprise, we propose determining the value of *EBT* deficit instead of the operating income deficit. This value is the sum of the short-received earnings before tax which is required for the indicators of each type of economic security to equal the set values (characteristic, critical, reference, boundary, threshold, set, planned, recommended, desired ones). Economic security indicators reflect various aspects of financial-economic activities of the enterprise. For instance, probability of bankruptcy and income adequacy are indicators of the financial components of economic security; labor efficiency and workforce availability ratios are indicators of the personnel component.

We believe the indicator of deficit of earnings before tax (*EBT*) to be relevant for assessment of the economic security level of the enterprise as from the analytical point of view it contains all the advantages as the net income but the results obtained on the basis of its calculation may be used for comparing similar data of enterprises with various taxation modes.

It should be noted that if the financial result of an enterprise's activity for the assessment period is losses (i.e. the actual value of *EBT* (*EBTa*) is negative ($EBTa < 0$)), the situation should be recognized dangerous. Therefore, further calculations of the economic security level are inexpedient.

It should be stressed that *EBT* deficit (ΔEBT) is characterized by the positive value which is determined through equating actual values of corresponding indicators to their set values. In this case the following condition is fulfilled:

$$\Delta EBT > 0. \quad (8)$$

If the calculation results show excess *EBT* value, i.e. $\Delta EBT < 0$, the following condition is accepted for further calculations of the economic security level of the enterprise:

$$\Delta EBT = 0. \quad (9)$$

The smaller the values of the sums of outstanding expenses (*OE*) and deficit of earnings before tax (ΔEBT) are, the higher economic security of an enterprise is.

Thus, considering the above, we suggest calculating the level of economic security of the enterprise ($L(EcS')$) by the formula:

$$L(EcS') = 1 - \frac{\Delta EBT + EO}{EBTr}, \quad (10)$$

where ΔEBT is the value of deficit of *EBT* which is required for the indicators of each type of economic

security to reach the values set by enterprise management (or by other means), USD:

$$\Delta EBT \rightarrow min. \quad (11)$$

EO is the amount of outstanding expenses, USD;
EBTr is the reference amount of the *EBT* indicator, USD:

$$EBTr = EBTa + \Delta EBT, \quad (12)$$

where *EBTa* is the actual amount of the EBT indicator, USD.

To conclude about the level of economic security of an enterprise, it is reasonable to use the scale similar to the above mentioned: the higher the level of economic security of the enterprise is, the greater the value of the ($L(EcS')$) is and the closer it is to 1.

It should be noted that starting from 0.5, the level of economic security of the enterprise corresponds to the average one, starting from 0.75 it corresponds to the high level. We believe that these are the most relevant values on achieving which the personnel's innovation activity can be directed at ensuring sustainable development of the enterprise. Here, the degree of personnel's innovation potential should be considered. If its values are low, development of the enterprise will be encumbered or fail even at the average level of economic security (Table 5).

Table 5. The matrix of determining the type of enterprise development on the basis of comparison of the degree of personnel's innovation activity/inertia and the level of its economic security.

Grading scale		Level of economic security of enterprise	
		High ($0.75 \le L(EcS') \le 1$)	Average ($0.5 \le L(EcS') < 0.75$)
Personnel's innovation activity/inertia	High ($51 \le K_I \le 100$)	Innovative progressive development	Development based on innovations
	Low ($1 \le K_I \le 50$)	Development based on economic security	No development

Thus, comparison of the degree of personnel's innovation activity and the level of economic security of an enterprise enables determining not only the possibility of sustainable development but also its type.

3 Conclusions

The research conducted enables complementing the current concept of determinants of sustainable development with such components as personnel's innovation activity and economic security of an enterprise.

The suggested methodological principles of assessing economic security of an enterprise enable determining separately the dependent part of economic security of its internal stakeholders including its personnel, its owners and the area community. This approach is gaining topicality, as innovative activity of personnel who do not feel secure will not correspond to the level required to ensure sustainable development of the enterprise. The developed economic and statistic toolkit of assessing probable attitudes of the personnel to implementation of innovations enables considering the degrees recognizing the necessity of innovations and the personnel's awareness of innovation activities of the enterprise. Innovative-progressive development is only possible at simultaneous achievement of the high level of the innovation potential of the personnel and the high level of economic security while the low level of the innovation potential leads to lack of development at the moment of assessment even at the average level of economic security of the enterprise.

Thus, the approaches and the developed economic and statistic toolkit presented in the article are a new scientific solution to assessment of the degree of enterprise development depending on its economic security levels and innovation activity of the personnel.

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Fuzzy modeling in human resource management

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Abstract. This article discusses the theoretical aspects of evaluating personnel performance indicators in the development of the digital economy. Eight procedures were identified for a comprehensive assessment of staff performance. A mathematical apparatus was built for assess normative or average values of performing job duties, determine many specialties, assess the level of education, evaluate the levels of enterprise management, describe many posts, describe the correspondence and interchangeability of posts, evaluate additional characteristics of employees and describe many additional tasks and their characteristics. Allocated linguistic variables characteristics of employees. The structural model of data mining in HR process management was built. Highlighted the membership function of the input linguistic variables of the staff and conducted a description of linguistic variables.

1 Introduction

Today, business is forced to solve a whole range of complex and unique tasks. So, to solve the problems of increasing and stabilizing the management of economic facilities in modern conditions, new approaches and solutions are required, which determined the emergence of a new concept of the German economist Klaus Schwab, President of the World Economic Forum in Davos [1]. According to this concept, it is stated that we live in the era of the fourth industrial revolution, where the virtual world is combined with the physical world using information technology. The fourth industrial revolution is characterized by a change in economic relations and the widespread use of intelligent technologies (Cloud technologies, Big Data, artificial neural networks and fuzzy sets, data mining and others), which is the basis of the digital economy.

It should be noted that there are various approaches to the determination and measurement of the dynamics of the digital economy, and it is also difficult to assess its volume. According to estimates (https://www.emarketer.com/topics/topic/b2b), the share of the digital segment of the global economy in 2020 could be 23% ($ 17 trillion). This leads to the expansion and rapid development of the Internet market using Big Data, followed by modeling by fuzzy logic approaches.

Therefore, for successful management of economic facilities in the digital economy an important role is given to HR management systems (Human resources) which are able to offer a radically new mechanism that allows companies to remain competitive in the market.

The first direction is determined by the level of application of intelligent systems. High information technologies embrace the world and replace the classical methods of HR-process management. Robot programs are now being applied, offering employees of the enterprise to undergo an express interview or interview using yet expert systems.

The next direction is the analysis and evaluation of young professionals who are able to learn and solve modern problems. Now, new specialists up to 25 years of age who have completely different knowledge, interests and fundamentally different ideas about modern work are entering the labor market. Young specialists are able to quickly make managerial decisions and push new projects forward, and thereby increase the level of work in the enterprise.

In addition to these areas, it should be noted that for a long time HR management was aimed at standardization and versatility. However, this approach is gradually becoming obsolete today. This approach is being replaced by HR management methods that are focused on the maximum use of the intellectual capital of employees. This is stimulated with the simultaneous satisfaction of individual needs, desires, employee capabilities and their synchronization with the tasks of the enterprise. Modern HR specialists are beginning to more closely monitor the development of employees within the enterprise, which allows flexible management of career growth, which can be adjusted taking into account the proposals of the employees themselves.

2 Formal problem statement

HR strategy is part of the overall strategy of enterprises and long-term planning of their business activities. An important role in these plans is played by assessments of the degree of personnel efficiency as a factor in updating and increasing production efficiency in the overall economic strategy of an enterprise. The creation of

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modern catalogs of employee data and their management requires the processing of a large amount of information. This is due to a wide range of organizational, economic and technical and technological tasks that are performed by personnel. Therefore, data analysis in the management of HR processes is an urgent task.

3 Literature review

The influence of information technology in the management of economic systems was presented in the work of S. Ivanov [2]. However, the problems of rating management have not been resolved. The solution to the problem of rating management was the work of Yu. Lysenko, V. Petrenko [3]. However, the level of staff development and their assessment were not considered. This work was devoted to the solution of this problem, in which the theoretical aspects of personnel development are studied, in particular, the concept, main tasks and directions of personnel development at the enterprise. V. Helman [4] considers the development of enterprise personnel as a change in its qualitative characteristics, in which indicators in the form of degree of activity were proposed.

Human resource management as a strategic human resource management today is seen as going beyond the boundaries of management tasks, such as motivation, the level of remuneration. Instead, managers need to consider HR management as a process that contributes to the success of the enterprise. Therefore, the work of Brian E. Becker [5] considers approaches where all managers should be involved in the management process, where the role of employees is important for the competitive advantage of the enterprise. In addition, organizations that value their skilled employees are more profitable than those that do not. Mark A. Huselid [6], Jeffrey Pfeffer and John F. Veiga [7]. The results of the work show that successful enterprises have several common characteristics: stable job security, the use of self-government methods, perfect pay and access to information. These tasks were considered in the work of Brian E. Becker, Mark A. Huselid [8], when an enterprise develops and motivates the development of human capital. The most successful enterprises manage HR as a strategic asset, and evaluate the effectiveness of labor resources in terms of its impact. When each employee of the enterprise effectively fulfills his duties and creates a high-performance work system in which the employee has the maximum involvement and responsibility of Dennis R. Briscoe [9].

In modern enterprises, an important task is to ensure a balance between the need for coordination and synchronization of units located both in different cities and around the world, which was reviewed by Randall S. Schuler, Pawan S. Budhwar, and Gary W. Florkowski [10]. Achieving this balance is becoming increasingly difficult as the level of functional diversity to which enterprises are exposed increases.

Today, new intelligent technologies are emerging to solve these problems. Such intelligent technologies include research and project management recommendations. Such works include the works of S. Gottwald [11].

These projects on improvement of resource processes are the ones of the most important tasks of production in enterprise management. Currently, the number of works in this direction is increasing by the D. Mukhamediyeva [12] and W. Siler, J. Buckley [13]. The obvious advantage of the proposed methods is the use of mathematical tools, the theory of fuzzy sets, which allows implementing the process of selecting conditions, the introduction of the method in the managerial processes of the enterprise. It should be noted that this work did not solve the problem of data mining in HR-process management with the possibility of modeling the degree of personnel efficiency, which determined the topic and relevance of this article.

4 The purpose of the article

The article is devoted to the analysis of the level of staff performance. The process of determining new, corrective, and available useful knowledge based on the theory of fuzzy sets.

5 Modelling HR-management

The task of fuzzy modeling and data mining when managing HR processes is to efficiently extract and analyze the existing data array of employees with subsequent management of personnel using cloud solutions. This will allow the rapid implementation of a new personnel management system, obtaining a new level of accessibility and increasing its mobility.

The resulting performance indicators of personnel at the enterprise can be represented in the form of multidimensional structures, where each measurement is represented by the corresponding indicators of the enterprise management system.

The following method of modeling human resources is proposed, which is presented in Fig. 1.

The proposed method includes four stages. The first stage solves the problem of choosing the analyzed indicators. For this, a lot of ratings are determined:

$$P = \{p_i = (op1, op2, ep1, ep2, ep3)\}, i = \overline{1, N}\ , (1)$$

where $op1$ is a generalized indicator of job compliance, characterizing the degree of conformity of qualifications and work experience of the post, level of responsibility, as well as the quality of the performance of current work and duties,

$op2$ – a generalized indicator of diligence, characterizing the effectiveness of the tasks (complexity, quality, timeliness),

$ep1$ – ambitiousness, a single indicator of personality characteristics,

$ep1$ – the quality of a leader, an indicator of personality characteristics,

$ep3$ – the level of attitude in the team, a single indicator of personality characteristics.

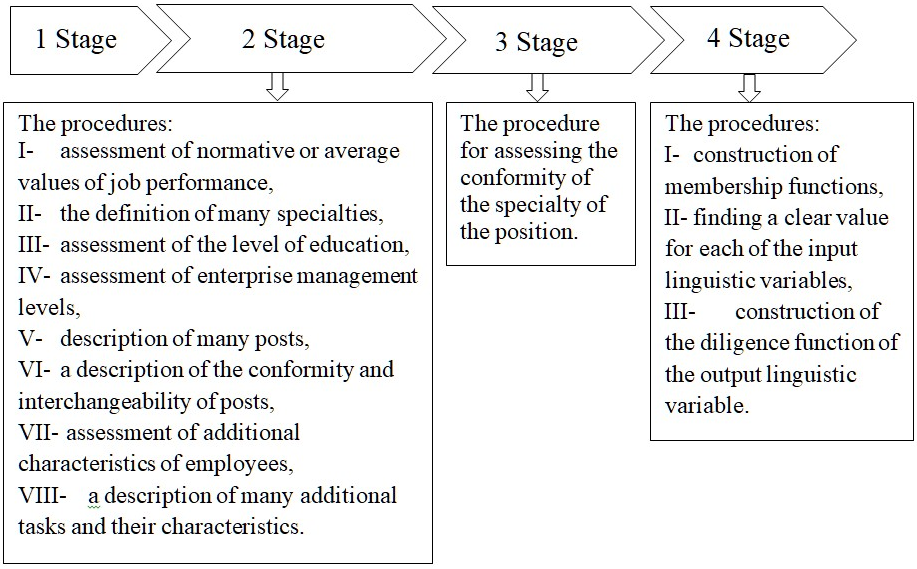

Fig. 1. The method of modeling human resources in fuzzy management.

At the second stage, the initial information is determined, which is necessary for calculating indicators based on expert assessments, analytical indicators (for example, work experience, quality of work performed, and others).

To describe the formalized set of sets of source information, we introduce the rules, namely, if the set $P = \{p_i = (op1, op2, op3)\}$, is defined, then to use the value of the component op02 of unit level 0, we will use the notation $op2$ (join operator)

At the second stage, procedures are applied that allow:

The first (I) procedure allows you to evaluate the regulatory or average value of the performance of official duties by employees – *P*0:

$$\mathrm{P0} = \{\mathrm{p0_i} = (\mathrm{op01}, \mathrm{op02})\}, \mathrm{i} = \overline{1, \mathrm{N}}, \qquad (2)$$

where $op01$ normative or average value of the job performance of the *i*-th employee,

$op02$ – normative or average value of the level of assessment of the performance of tasks of the *i*-th employee.

The second (II) procedure is aimed at identifying many specialties (economist, programmer, builder and others) – SP:

$$SP = \{sp_r\}, r = \overline{1, L^{sp}}, \qquad (3)$$

where sp_r – is the *r*- th specialty,

L^{sp} – is the number of specialties.

The third procedure allows you to assess the level of education (secondary, bachelor, master and others) –*UO*:

$$\mathrm{UO} = \{\mathrm{uo_v} = (\mathrm{name}, \mu), \mathrm{v} = \overline{1, \mathrm{L^{uo}}}, \qquad (4)$$

where uo_v – is the vector of characteristics of the *v*-th category,

$name$ – category name,

μ – assessment of the level of education for the category in points,

L^{uo} – is the number of categories.

The fourth (IV) procedure is aimed at assessing the level of enterprise management (higher, middle and lower level) – UD:

$$\mathrm{UD} = \{\mathrm{ud_w} = (\mathrm{name}, \gamma)\}, \mathrm{w} = \overline{1, \mathrm{L^{ud}}}, \qquad (5)$$

where ud_w- is the vector of characteristics of the *w*-th level,

$name$ – level name,

γ – is an estimate of the level in points,

L^{ud} – the number of levels, which is determined by the scale of the enterprise.

The fifth (V) procedure solves the problem of describing many positions in the enterprise – D:

$$\mathrm{D} = \{\mathrm{d_j} = (\mathrm{name}, \mathrm{ud}, \mathrm{uo}, \mathrm{kl}, \mathrm{SPD}) : \mathrm{ud} \in \mathrm{UD}, \mathrm{uo} \in \mathrm{UO}\}, \mathrm{j} = \overline{1, \mathrm{L^d}}, \qquad (6)$$

$$\mathrm{SPD} = \{\mathrm{spd_r} = (\mathrm{sp}, \beta) : \mathrm{sp} \in \mathrm{SP}, 0 \le \beta \le 1\}, \mathrm{r} = \overline{1, \mathrm{L_j^{spd}}}, \qquad (7)$$

where d_j is the *j*-th position,

$name$ – job title,

ud – position level in the organizational and staff structure of the enterprise,

uo – the level of education required for the *j*-th position,

kl – required work experience (minimum number of years) in a given position for an optimal qualification level,

SPD – many specialties related to this position,

spd_r is the vector of the correspondence characteristics of the *r*-th specialty of the *j*-th position β,

β – is the correspondence coefficient of the specialty sp of the *j*-th position,

L^d – is the number of posts,

L_j^{spd} – number of specialties in the *j*-th position.

The sixth (VI) procedure solves the tasks of describing correspondence and job interchangeability – SD:

$$SD = \{sd_f = (d1, d2, \alpha): d1 \in D, d2 \in D\ 0 \le \alpha \le 1, \forall(d1 = d2) \Rightarrow \alpha = 1\}, f = \overline{1, L^{sd}}, \quad (8)$$

$$L^{sd} = (L^d)^2, \quad (9)$$

where sd_f – is the f-th vector of job matching characteristics $d1$ and $d2$,

α – is the compliance coefficient.

The seventh (VII) procedure is aimed at assessing additional characteristics of employees – A:

$$A = \{a_i = (ds, ST, OB): ds \in D, uo \in UO\}, i = \overline{1, N}, \quad (10)$$

$$ST = \{st_j = (d, kL): d \in D, d \in UO\}, j = \overline{1, L_i^{st}}, \quad (11)$$

$$OB = \{ob_w = (sp, uo, god): sp \in SP, uo \in UO\}, w = \overline{1, L_i^{ob}}, \quad (12)$$

where a_i – is the vector of characteristics of the i-th employee,

ds – the position held by the employee,

ST – many posts in which the employee previously worked and experience in them,

st_j – vector of characteristics of work experience in previous positions,

kL – length of service (number of years) in the position d,

OB – value, reflects the education received by the i-th employee; sp – specialty; uo – level of education,

god – year of receipt of the qualification document (certificate, certificate, diploma and others),

L_i^{st} – the number of posts previously held by the i-th employee,

L_i^{ob} – the number of specialties in which the employee was educated by the i-th employee.

The eight (VIII) procedure allows you to describe many additional tasks (determined by orders) and their characteristics in the enterprise:

$$Z = \{z_k = (t0, tk, tk', usz), 0 \le \beta \le 1\}, k = \overline{1, M}, \quad (13)$$

where z_k – is the vector of characteristics of the k-th task,

$t0$ and tk – the value of the beginning and end of tasks, determines the term for completing the task in units of measurement of working time (for example, working days, hours and others),

tk' – the value of time, determines the critical deadline for completing the task, after which the task is either canceled or transferred to another performer,

usz – task difficulty level,

M is the number of tasks.

The set of completing additional IZ tasks by employees can be written as follows:

$$IZ = \{iz_k = (a, z, uv^p, uv): a \in A, z \in Z, 0 \le uv^p \le 200\}, k = \overline{1, M}, \quad (14)$$

where iz_k is the characteristic of the k-th job,

a – an employee who performs additional tasks,

z – the task

uv^p – is the percentage of the task according to the plan at the current time t ($uv^p = 0$ at time $t0$, $uv^p = 200$ at time k),

uv – is the percentage of the task at the current time t.

In case of failure to perform additional tasks, the value of $IZ = 0$.

At the third stage, the procedure for assessing the conformity of the specialty of the position is performed. The function $f\beta$ returns the value of the correspondence of the specialty xsp to the position xd:

$$f\beta(xsp, xd) = \begin{cases} d_{j0}.spd_{i0}.\beta, \exists j_0, r_0: (d_{j0} = xd) \wedge (d_{j0}.spd_{r0}.sp = xsp) \\ 0, \neg\exists j_0, r_0: (d_{j0} = xd) \wedge (d_{j0}.spd_{r0}.sp = xsp) \end{cases}. \quad (15)$$

The function fα returns the value of the coefficient of correspondence and interchangeability of the post xsp post xd:

$$f\alpha(xds, xd) = \begin{cases} sd_g\alpha, \exists g_0: (sd_{g0}.d1) \wedge (sd_{g0}.d2 = xd) \\ 0, \neg\exists g_0: (sd_{g0}.d1) \wedge (sd_{g0}.d2 = xd) \end{cases}. \quad (16)$$

To determine job conformity is the level of education of the position held in conjunction with work experience in similar or related positions:

$$p_i.op1 = \delta(op11 \cdot op12) \cdot op13, \quad (17)$$

$$op11 = \sum_{w=1}^{L_i^{ob}} f\beta(a_i.ob_w.sp, a_i.ds) \cdot \frac{a_i.ob_w.god}{godT}, \quad (18)$$

$$op12 = \sum_{j=1}^{L_i^{st}} f\delta(a_i.ds.f, a_i.st.d) \cdot \frac{a_i.st_j.kL}{a_i.ds.kL}, \quad (19)$$

where $godT$ – is the value of the current year,

$op11$ – qualification level of education received,

$op12$ – qualification level, which is determined by work experience,

$op13$ – quality of job performance, determined by an expert.

When solving the problem of data mining in the management of HR processes, fuzzy logic methods are used to display the result on the interval [0; 1].

Therefore, at the fourth stage, the procedure for constructing membership functions based on the theory of fuzzy sets is performed.

The following “position”, “level”, “education” can be attributed to numerical linguistic variables of employees, and “conflict”, “level of substitution” to linguistic variables. Numerical linguistic variables and their meanings serve for a qualitative description of a quantitative quantity. The values of linguistic variables are determined by experts.

It should be noted that a linguistic variable, like its original term set, is associated with a specific dimensional scale on which all arithmetic operations are defined.

To assess the characteristics of employees in table 1, linguistic variables and their dimensions are proposed.

The use of the concept of stimulation and destimulation is applied taking into account the influence on the degree of personnel efficiency, namely,

stimulation – the effect on the increase and destimulation – on the reduction of the factor.

Table 1. The linguistic variables of employee characteristics.

Term set	The metric and type of exposure	x^1_{min}	x^1_{max}	The term designation
$T^1_1 = \cup T^j_1$, $j = \overline{1,3}$	Performance of duties <position> – stimulation	0	1	Not performed Partially completed Performed
$T^1_2 = \cup T^j_1$, $j = \overline{1,3}$	Job Interchangeability <Interchangeability Level>, discouragement	1	3,0	Low Average High
$T^1_3 = \cup T^j_1$, $j = \overline{1,3}$	Level of education <education>, stimulation	1	3,0	Secondary education Bachelor Master
$T^1_4 = \cup T^j_1$, $j = \overline{1,3}$	Conflict <conflict>, stimulation	0	3,0	Low Average High
$T^1_5 = \cup T^j_1$, $j = \overline{1,3}$	The importance level of the specialty <SpecialtyLevel>, discouragement	0	0,5	Low Average High

Therefore, the term set $T^n_i = \{T^{n\prime}_i\}$ is associated with the set $T^{n\prime}_i$, where $T^{n\prime}_i = \langle x, \mu_{T^{n\prime}_i}(x) \,/\, x \in [x_{min}, x_{max}]\rangle$ is a fuzzy number, $i = \overline{1,m}$, m is the number of term sets, n is the number of employees.

To eliminate the influence of changes in the input variables of the metrics and, as a consequence, the correction of term sets, a transition to a normalized function is proposed. Let the previously defined term set T_i be the original one.

The normalized linguistic variable is a mapping on the interval [0; 1]:

$$D^n_i = \{D^{n\prime}_i\}, D^{n\prime}_i = \langle z, \mu_{D'_i}(z) \,/\, z \in [0,1]\rangle, \quad (20)$$

where z is a fuzzy number corresponding to the term set D'_i on the interval [0; 1], n is the number of employees.

These functions allow you to display heterogeneous input variables in a single normalized interval [0;1], which allows you to reduce errors associated with different quantities and their dimensions. This provides a convenient representation of the values, as well as their interpretation.

The structural model of data mining in HR process management is presented in Fig. 2.

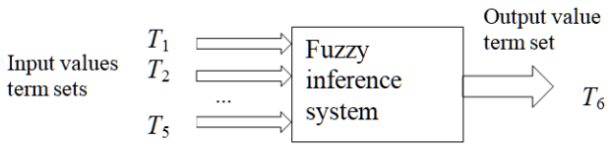

Fig. 2. The structural model of the model of data mining in the management of HR-process.

In the structural model, $T = \{Ti\}$ is a term set, where $i = \overline{1,n}$, n is the number of sets, each of which is represented by a fuzzy variable with a domain of definition X.

The process of modeling fuzzy values is based on a fuzzy inference system, which allows you to convert expert estimates into fuzzy values.

In the fuzzy inference system, the procedure for finding a clear value for each of the input linguistic variables based on defuzzification is applied. Defuzzification in a fuzzy inference system is the process of finding a value for each of the output linguistic variables of the set $W = \{x_1, x_2, .. x_n\}$. The task of defuzzification is that using the results of accumulation of all output linguistic variables, it is necessary to obtain a quantitative value of each of the output variables, which can be used in a fuzzy inference system relative to the input linguistic variable.

Under the accumulation of fuzzy inference is understood the process of finding the membership function for each of the output linguistic variables of the set.

Thus, the transformation of a fuzzy set into some specific values of variables, namely, leading to clarity is defuzzification.

The defuzzification procedure is performed by a sequence that considers each of the output linguistic variables β and the fuzzy set $T_i = \{T^j_i\}$ related to it. The result of defuzzification for the output linguistic variable is defined as a quantitative value.

The defuzzification process is considered complete when quantitative values are determined for each of the output linguistic variables. For the fuzzy inference system, the Mamdani algorithm was applied.

The Mamdani algorithm includes the following steps:
1) the formation of a rule base for fuzzy inference systems;
2) fuzzification of input variables;
3) aggregation of conditions in fuzzy rules to find the degree of truth of the conditions of each of the rules of fuzzy logic;
4) accumulation of conclusions of fuzzy production rules;
5) defuzzification of output variables based on the center of gravity method.

Depending on the nature of the domain *X*, numerical linguistic variables can be defined.

The values of linguistic variables are determined on an ordinal scale. It should be noted that a linguistic variable, like its original term set, is associated with a specific scale on which all arithmetic operations are defined. Therefore, the term set $T_i = \{T^j_i\}$ is associated with the set T^j_i, where $T^j_i = \langle x, \mu_{T^j_i}(x) \,/\, x \in [x_{min}, x_{max}]\rangle$, $i = \overline{1,n}$; $j = \overline{1,m}$; n is the number of term sets, m is the number of terms.

A model that satisfies these fuzzy sets is their union:

$$\mu T_i = sup\left(\mu_{T^j_i}(x)\right), T_i = \cup T^j_i. \quad (21)$$

We construct membership functions for the linguistic variable characteristics of employees, presented in table 1.

The process of converting experts' qualitative assessments into fuzzy quantities consists in mapping the

elements of the original term set in the form of constructing membership functions of fuzzy quantities $T_i^j \in T_i$.

The description of linguistic variables is as follows:

⟨position, {not fulfilled, partially fulfilled, fulfilled}, [0; 1]⟩,

⟨level of interchangeability, {low, medium, high}, [1; 3]⟩,

⟨education, {secondary, bachelor, master}, [1; 3]⟩,

⟨conflict, {low, medium, high}, [1; 3]⟩.

Moreover, the values of the sets are in the range [0; 1] & [1; 3].

The use of trapezoidal membership functions lies in the fact that the calculation uses the definition of fuzzy numbers. This is a form of analytical approximation using (LR) – functions that include the trapezoid functions. From this it follows that fuzzy numbers are determined to perform fuzzy modeling operations.

The constructed membership functions of the input linguistic variables are presented in Fig. 3.

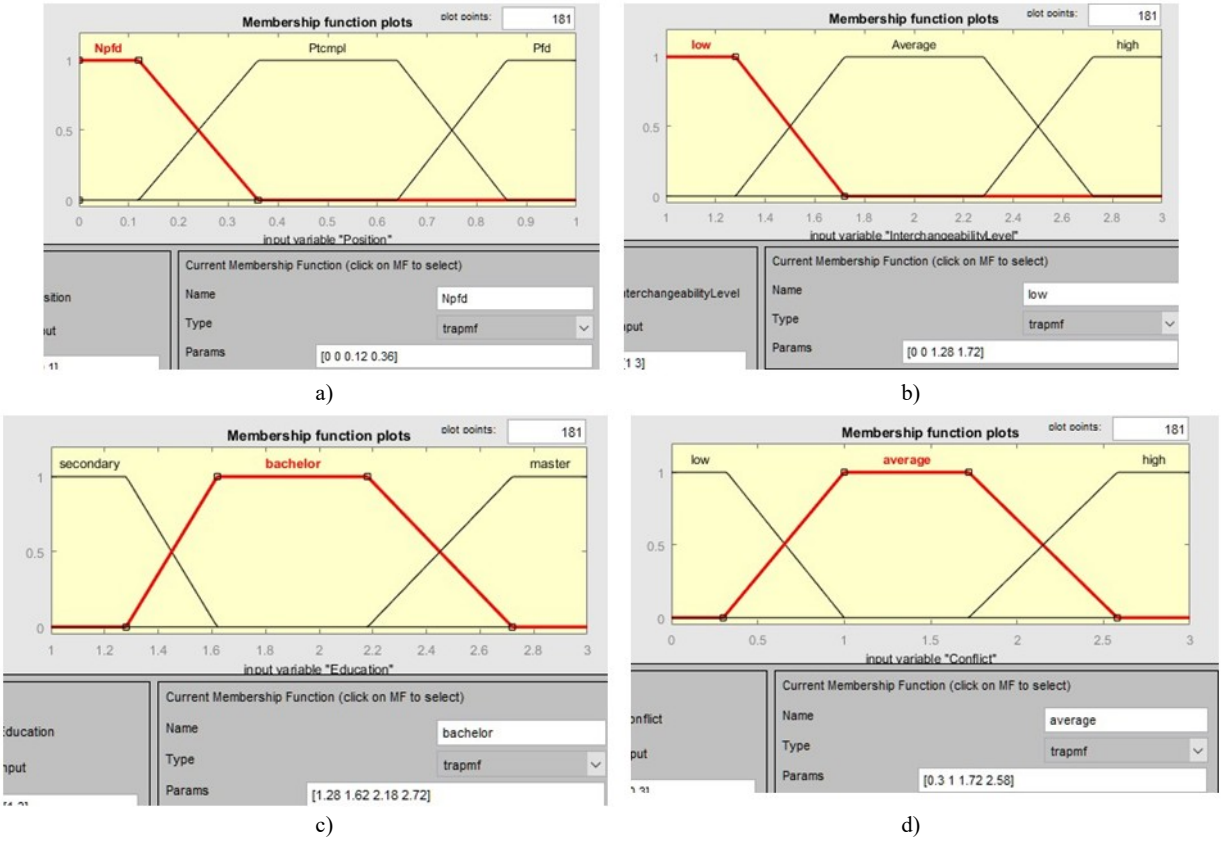

Fig. 3. The membership function of the input linguistic variables: a) "Fulfillment of duties", b) "Interchangeability of posts", c) "Level of education", d) "Conflict".

In the fuzzy inference procedure for managing HR processes, it is necessary to consider the work of employees at all levels of work. The fuzzy inference procedure is implemented in the MATLAB R2017a system, which allowed obtaining the following results of assessing the degree of personnel efficiency.

To perform the procedure, we built the diligence function of the output linguistic variable "assessment of the degree of personnel efficiency", which is presented in Fig. 4.

The simulation results of assessing the degree of personnel efficiency, which is presented in Fig. 5.

The authors of the article propose a solution to the problem of constructing a data analysis method in human resource management and modeling the assessment of the degree of personnel efficiency based on fuzzy sets.

6 Conclusion

The following method of data analysis in personnel management is proposed. The method includes four steps. At the first stage, the problem of choosing the analyzed indicators is solved. At the second stage, eight procedures are performed to solve the following problems: to assess the normative or average values of labor productivity, to determine many specialties, to assess the level of education, to assess the levels of enterprise management, to describe a lot of posts, to describe correspondence and job interchangeability, to evaluate additional characteristics of employees, to describe many additional tasks and their characteristics. At the third stage, the procedure for assessing the conformity of the specialty of the post is carried out. At the fourth stage, the procedure for constructing membership functions based on the theory of fuzzy sets is performed. The fuzzy inference procedure is implemented in the MATLAB R2017a system, which made it possible to assess the degree of personnel efficiency.

Prospects for the application of the method and

procedures of fuzzy modeling in human resource management are the expansion of approaches and the application of cloud computing models.

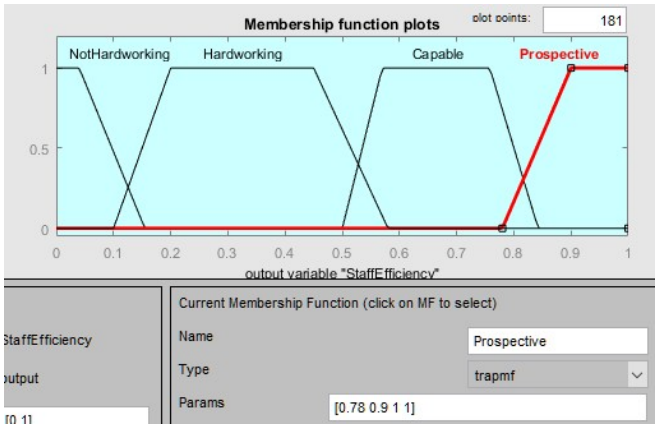

Fig. 4. The membership function of the output linguistic variable “assessment of the degree of personnel efficiency”.

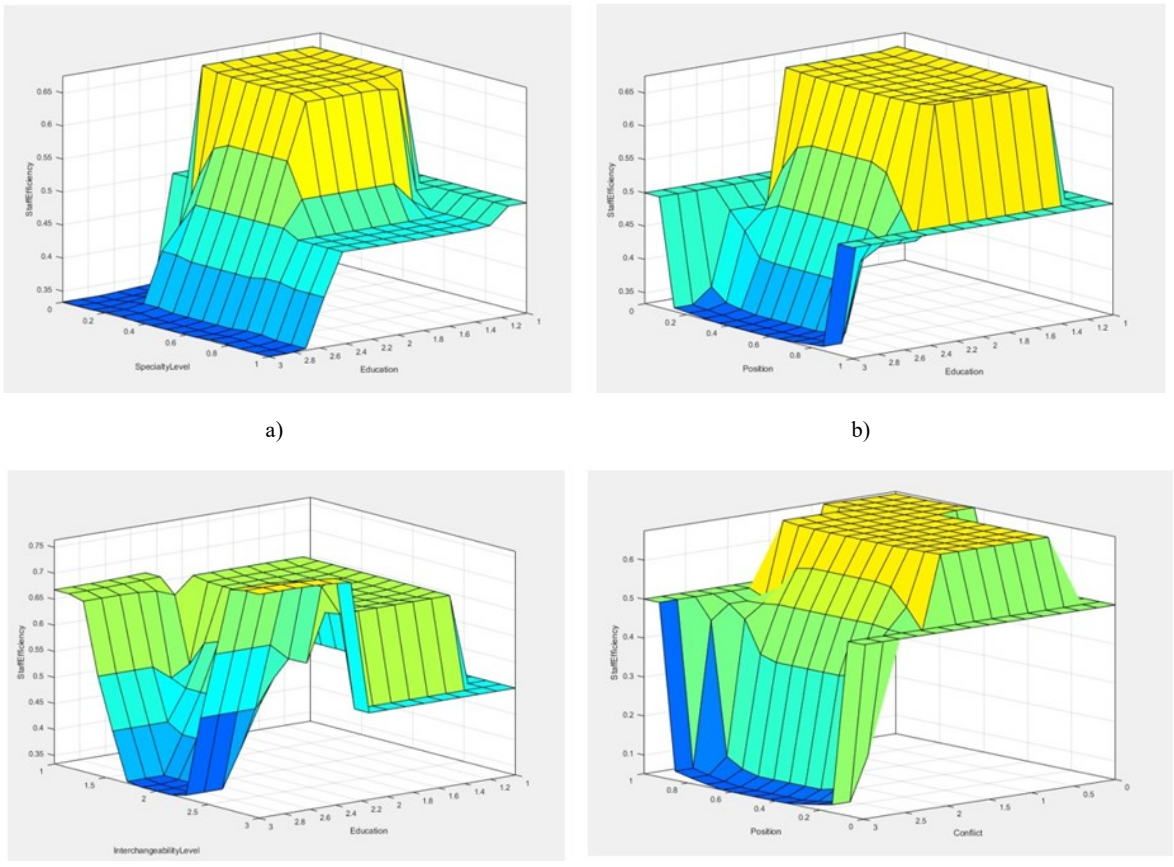

Fig. 5. Modeling the assessment of the degree of personnel efficiency: a) the level of importance of the specialty and education, b) the level of fulfillment of duties and education, c) the level of interchangeability of posts and education, d) the level of fulfillment of duties and conflict.

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Innovative development of human capital in the conditions of globalization

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Abstract. The role of human capital in the innovative development of the Ukrainian economy, which is formed through investment in the human being, is investigated. It is determined that an indispensable condition for sustainable development of the country is the implementation of the strategy of increasing the quality of human capital, which is actively involved in innovation processes and serves as a key resource for improving the competitiveness of the national economy. Emphasis is placed introduction of the model "life-long learning" using modern technologies. A methodological approach to determining the level of innovative development of human capital is proposed and the value of the integral index of innovative development of human capital is calculated. The innovative-investment model of human capital development in the conditions of globalization is developed and the directions are defined. To overcome the problems of inefficient development of human capital and to improve its quality, a set of measures will be proposed that will contribute to the innovative development of the economy. The scientific novelty is to deepen theoretical provisions and to develop scientific and practical recommendations for improving the quality of human capital and its innovative development in the context of accelerating globalization processes.

1 Introduction

The integration of Ukraine into the international economic space, where globalization is accelerating and competition between countries is increasing, has led to the need to form an innovative model of the economy. An indispensable condition for sustainable development, ensuring a high-tech competitive environment is the innovative development of the country, which is a paramount strategy in post-industrial society. The realization of a certain strategy is possible only if the quality of human capital is increased, where the creative potential of the person, mental abilities, knowledge, professionalism comes to the fore. As a person with his intellect creates and implements innovations, takes an active part in innovation processes, the development and improvement of the quality of human capital is a prerequisite for building an innovation and investment model of an economy in the conditions of sustainable development, which made the current research relevant.

Of particular importance is the development of the educational component of personality. The introduction of the "life-long learning" model and the efficient use of highly skilled labor resources will in the future increase the competitive advantages of the national economy.

The purpose of the article is to identify the main tools for innovative human development as a key factor in increasing the competitiveness of the national economy, to build an innovation-investment model of human capital development and to identify priority areas for improving its quality in a globalized environment.

The realization that a person is at the center of all economic processes and acts as a major factor in the innovative development of the economy, the requirements for the quality of human capital are increasing. Today in Ukraine there is a transition to the information society, which is characterized by the growing role of intellectual activity of man, his ability to innovate. The result of such activities is the creation of high-tech products, which is key to shaping the country's GDP. Therefore, the formation of innovative human capital and the definition of its development prospects in modern conditions require further scientific research.

The theory of human capital has been gradually developed in accordance with the stages of development of world economic theory and conditions of social production, which focuses on the intellectual, creative and productive qualities of man as the main factor of economic growth. The concept of human capital was introduced into science in the 1960th. The founders of the human capital theory are G. Becker [1-2] and T. Schultz [3-4].

T. Schultz [3] first used the term "human capital". He noted that education is a form of capital. In his view, human capital is a set of knowledge, abilities, motivations that are the source of future income and enjoyment. T. Schultz [4] argued that investing in a person is an investment in education, health care, and

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science. T. Schultz [4] believed that the educational level of a person influences the ability to use new technologies, information that will provide competitive advantages of economic development. For the first time, T. Schultz proved that human capital is capable of accumulation and reproduction. T. Schultz [4] considered human capital at the macro level, that is, at the level of the country's economy.

G. Becker [1-2] investigated this category at the micro level, i.e. at the enterprise level. G. Becker [1] created a theoretical basic model of human capital as a set of knowledge, skills, skills and expanded the definition of this category. G. Becker [2] Proposed for human capital assessment to take into account investments not only in education, science, health care, but also the costs of training and retraining in manufacturing, computer training, physical and spiritual development, as well as indirect costs in the form of lost income during the period of study.

Many scholars have explored the theory and methodology of human development, but there is no consensus on human capital development. A significant contribution to the theoretical and methodological development of problems of human capital development was made by famous foreign scientists H. Bowen [5], L. Thurow [6], F. Machlup [7], J. Mincer [8] and others.

Considerable attention was paid to the issues of formation, use and innovative development of human capital by domestic scientists. O. Amosha, A. Degtyar [9] formed a methodological aspect of human capital in the conditions of an innovative economy. V. Antoniuk [10] studied socio-economic assessment and development assurance of the formation and use of human capital in Ukraine. M. Bublyk, O. Rybytska [11] examined the pollution impact on the mortality rate in Ukraine. Methodological bases of human, intellectual and social capital development assessment are presented by O. Grishnova [12]. E. Libanova [13] investigated the influence of social and demographic factors of human development and modernization of the national economy, A. Turilo [14] proposed the concept of human capital assessment and management. The impact of human capital on the innovation capacity of companies is investigated by L. Lavrinenko [15]. R. M. Mariz-Pérez, M. M. Teijeiro-Alvarez, M. T. García-Alvarez [16] investigated the relevance of human capital as a driver for innovation.

H. McGuirka, H. Lenihanb, M. Hartc [17] measured the impact of innovative human capital on small firms' propensity to innovate. C. Diebolt and R. Hippe [18] established the long-run impact of human capital on innovation and economic development in the regions of Europe. Ł. Bryl [19] conducted a comparative analysis of US corporations in the human capital orientation and financial performance. T. H. Aas and K. J. Breunig [20] built a contingency perspective of conceptualizing innovation capabilities. T. Kraśnicka, W. Głód and M. Wronka-Pośpiech [21] explained the nature of management innovation and proposed five-dimension management innovation model: strategic dimension, structural dimension, employee motivation and development dimension.

2 Innovative development of human capital as a basis for sustainable economic development

In the context of globalization transformations, the modern paradigm of innovative development of human capital is a key lever of increasing the competitiveness of the country, a major factor in the development of an innovative and investment model of state development [22]. With the development of scientific and technological progress, information and communication technologies, human capital occupies a central place as a carrier of intelligence, knowledge, skills, experience, and professionalism.

Human development is a continuous process of qualitative and quantitative changes that lead to an increase in the level of education, culture of man, his mental and spiritual maturity. Innovative development of human capital is characterized by fundamentally new approaches that are embodied in the introduction of a new model of "life-long learning" and the formation of a new model of working life, where the main focus is innovative work; the application of social technologies, innovative forms of employment, the use of new models of working time, etc. Increasing investment in human development (from the state, business, personality) leads to an increase in its level of intellectualization, which is the basis for sustainable economic development.

Foreign experience [23] shows that the formation of an innovative model of economic development requires the introduction of a regulatory policy of the state aimed at the development of institutions that will provide a favorable microclimate for the innovative development of human capital, enhancing its competitiveness.

Global studies on the level of innovative development of countries have been conducted since 2007 as part of a joint project of INSEAD International Business School, Cornell University and the World Intellectual Property Organization (WIPO) [24-26]. The Global Innovation Index is defined as a set of indicators that characterize the level of innovative development of countries in the world at different levels of economic development. The calculation methodology includes 80 parameters, grouped in two directions (index calculation is defined as a weighted sum of estimates of two groups of indicators - from 0 to 100): 1. Available resources and conditions for innovation (Innovation Input): Institutes; human capital and research; development of the internal market; infrastructure; business development. 2. Outcomes of Innovation Output: Development of Knowledge and Technology Economy; results of creative activity implementation.

The ranking of the world countries according to the Global Innovation Index, which allows evaluating the effectiveness of efforts to introduce and develop innovations in a country, is presented in Table 1 [24-26].

Table 1 data shows that over the 2017-2019 period among other countries of the world that participated in the Innovation Survey, Ukraine improved its position from 50 places to 47, although it lost four positions compared to 2018 (where it was 43 place). The Global

Innovation Index in 2019 was 37.40, but it is the least significant compared to previous years. This indicates a lack of use of resources and the innovative potential of the country. The leaders of the world in the Global Innovation Index are the developed countries: Switzerland, Sweden, the Netherlands, the United States of America, the index of which exceeds 60 points. Ukraine's economy is much inferior to other developed countries in terms of innovative development.

Table 1. Global Innovation Index Rankings 2017-2019.

Country	2017		2018		2019	
	Rank	Innovation Index	Rank	Innovation Index	Rank	Innovation Index
Switzerland	1	67,69	1	68,40	1	67,24
Sweden	2	63,83	3	63,08	2	63,65
Netherlands	3	63,36	2	63,32	4	61,44
United States of America	4	61,40	6	59,81	3	61,73
United Kingdom	5	60,89	4	60,13	5	61,30
Germany	9	58,39	9	58,03	9	58,19
Ireland	10	58,13	10	57,19	12	56,10
Japan	14	54,72	13	54,95	15	54,68
Canada	18	53,65	18	52,98	17	53,88
Norway	19	53,14	19	52,63	19	51,87
China	22	52,54	17	53,06	14	54,82
Belgium	27	49,85	25	50,50	22	50,18
Poland	38	41,99	39	41,67	39	41,31
Turkey	43	38,90	50	37,42	49	36,95
Russian Federation	45	38,76	46	37,90	46	37,62
Ukraine	**50**	**37,62**	**43**	**38,52**	**47**	**37,40**
Armenia	59	35,65	68	32,81	64	33,98
Georgia	68	34,39	59	35,05	48	36,98
Belarus	88	29,98	86	29,35	72	32,07
Tajikistan	94	28,16	101	26,51	100	26,43
Yemen	127	15,64	126	15,04	129	14,49

The implementation of innovation policy depends on the effectiveness of the state regulatory policy, based on which regulatory acts are adopted, namely the Laws of Ukraine "On Innovative Activity", "On Priority Areas of Innovative Activity in Ukraine", "On the National Program of Informatization", "On Higher Education", "On Education", "On the National Strategy for the Development of Education in Ukraine until 2021", Strategy for development and utilization of labor potential in Ukraine for the period up to 2025, etc.

3 Tools for innovative development of human capital

The main tools for innovative development of human capital are [27-28]: 1. Legal instruments (laws, regulations, strategies, and programs in the direction of innovative development of human capital). 2. Financial instruments. Government expenditures for: health care; education and vocational training; spiritual and physical development of human capital; social protection of the population, etc. 3. Tools for raising the educational and professional level of human capital. The country has a national educational policy, the tools of which are: educational programs, licenses, accreditations, dual education, educational innovative technologies. Modern tools of human resources are E-learning – distance learning, corporate university (business education), online lectures and more. There are innovative forms and types of employment (outsourcing, outstaffing, outplacement, staff leasing, coworking, personnel audit, HR consulting, etc.). 4. Infrastructure development tools (venture and innovation funds, technoparks and science parks, start-ups, online information resources, patented government agencies, innovation promotion marketing centers, etc.). 5. Instruments of social influence (social technologies and projects: "adaptation technology of young specialists", "technology of conflict resolution", "technology of recruitment", "technology of certification of specialists", technologies of search of management strategy, technologies of social modeling and forecasting, information technologies, Employee Social Card, gamification (search for custom solutions, etc.).

4 A methodological approach to determining the level of innovative development of human capital

In many works, both foreign and domestic scientists have laid the methodological foundations for assessing the development of human capital. The study of theoretical and methodological approaches to assessing the development of human capital has made it possible to determine that the most common method is the integral evaluation of the indicator.

Analyzing methodological approaches [29] to assessing the development of human capital necessitated the development of its methodology, which would allow taking into account modern requirements for human capital in the conditions of the innovative economy taking into account the tendencies of globalization.

We propose our methodological approach to determining the integral index of innovative development of human capital, which has the following algorithm:

Step 1. Determination of analytical indicators that influence the innovative development of human capital, bringing them to a single measure.

Step 2. Selection of factors of influence and verification of their values on multicollinearity using the economic-mathematical method of constructing a matrix of paired correlation coefficients (correlation matrix), which has the following form (formula 1):

$$k^* = \begin{vmatrix} k_{yy} & k_{yx_1} & k_{yx_2} & k_{yx_3} & \dots & k_{yx_m} \\ k_{x_1y} & k_{x_1x_1} & k_{x_1x_2} & k_{x_1x_3} & \dots & k_{x_1x_m} \\ k_{x_2y} & k_{x_2x_1} & k_{x_2x_2} & k_{x_2x_3} & \dots & k_{x_2x_m} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ k_{x_my} & k_{x_mx_1} & k_{x_mx_2} & k_{x_mx_3} & \dots & k_{x_mx_m} \end{vmatrix}. \quad (1)$$

Even correlation coefficients estimate the relationship between pairs of variables: independent x_i and dependent y (k_{x_iy}), independent x_j and dependent y

(k_{x_jy}), independent variables x_i and x_j ($k_{x_ix_j}$). The correlation matrix of pairwise regression coefficients is symmetric $k(k_{x_i}k_{x_j})$ (formula 2):

$$k_{xx} = X^{*\prime}X^{*} \quad (2)$$

The elements of this matrix show the close relationship of one variable with another.

Step 3. Normalization of values of indicators that will ensure their comparability (Z_{ij}). They are broken down into stimulus and stimulus metrics:

1) For indicators-stimulants (formula 3):

$$Z_{ij} = \frac{X_{ij}-X_{jmin}}{X_{jmax}-X_{jmin}} \quad (3)$$

where X_{ij} – the value of the *j*-th indicator in the *i*-th period; X_{jmin} – the minimum value of the *j*-th indicator in the *i*-th period; X_{jmax} – the maximum value of the *j*-th indicator in the *i*-th period.

The stimulus value ranges from 0 to 1, where 0 is the worst value, 1 is the best value. Its growth contributes to an increase in the index of the innovative development of human capital.

2) For indicators-stimulators (their growth decreases the index of human development) (formula 4):

$$Z_{ij} = \frac{X_{jmax}-X_{ij}}{X_{jmax}-X_{jmin}} \quad (4)$$

The determined stimulus is between 0 and 1, where 0 is the worst value, 1 is the best value.

Step 4. Calculation of the weight value of each indicator using the economic-mathematical method of determining the correlation coefficients (formula 5):

$$\sum_{j=1}^{n} v_j = 1 \quad (5)$$

Step 5. Determination of partial indices of innovative development of human capital (formula 6):

$$I_{ij} = \sum_{j=1}^{n} Z_{ij}v_j \quad (6)$$

where Z_{ij} – a normalized *j*-th indicator of human development in the *i*-th period; v_j – the weight with which the *j*-th index is calculated when determining the integral index; *n* – number of indicators.

Step 6. Determination of the integral index of innovative development of human capital P_{innov} (formula 7):

$$P_{innov} = \sum_{j=1}^{n} I_{ij} \quad (7)$$

The calculation of the integral index of the innovative development of human capital is presented in Table 2. The integral indicator of the innovative development of human capital is graphically presented in Fig. 1.

As can be seen from the data in Table 1 and Fig. 1, the integral index of the innovative development of human capital for the analyzed period decreases, which is a negative trend. In the country, there is a decrease: the number of employees involved in the implementation of research and development; the number of graduates of higher education institutions and the number of graduate and doctoral students. The declining trend of the innovative development of human capital leads to a deterioration of the quality of human capital, which negatively affects the GDP of the country, reducing the competitive advantages of the national economy.

Table 2. Estimated values of the integral index of the innovative development of human capital.

Years	Number of employees involved in the implementation of research and development, thousands of persons	Issued specialists from the HEA, thousand people	Number of graduate students, thousand people	Number of doctoral students, thousand people	Share of the number of innovators in the total number of industrial enterprises,%	Integral indicator of innovative development of human capital
2010	182,484	543,7	34,653	1,561	11,5	0,792
2011	175,33	529,8	34,192	1,631	12,8	0,798
2012	164,34	520,7	33,64	1,814	13,6	0,782
2013	155,386	485,1	31,482	1,831	13,6	0,670
2014	136,123	405,4	27,622	1,759	12,1	0,377
2015	122,504	374,0	28,487	1,821	15,2	0,440
2016	97,912	318,7	25,963	1,792	16,6	0,306
2017	94,274	359,9	24,786	1,646	14,3	0,233
2018	88,128	357,4	22,829	1,145	15,6	0,211

5 Correlation-regression model of innovative development of human capital

To establish the relationship between the factors influencing the innovative development of human capital, a multivariate least-squares regression model was constructed using a methodological model proposed by scientists [29] for constructing models. The results of the calculations are given in Table 3.

Table 3. An econometric model of innovative development of human capital.

Indicator (dependent variable Y)	Model	Adequacy of Fisher's models	Student's t-test
GDP	Y = -1,0121+0,0203*X1+ 0,0196*X24+4,0425*10^-06*X3, R^2=0,928	17,0936 >F (0,0096)	5,850>t (2,776)

Table 2 data show that a considerable number of factors, both direct and indirect, influence on the development of human capital are taken into account in economic and mathematical models. The factors selected were the most significant in its development. The constructed multivariate regression models show that the correlation between the factors exists and is sufficiently stable. The multiple determination coefficient indicates how much the resultant index depends on the factor traits.

All models were tested for adequacy using the Fisher and Student t-test, which are compared with the table values.

The coefficients of the equation show the quantitative influence of each factor (with the invariance of the others) on the resultant index. The greater the modulus of the value of the coefficient of the independent variable, the greater the impact it has on the resultant index.

Analyzing the model of the influence of factors of development of human capital on the growth of GDP of the country made it possible to determine that the resultant GDP is the greatest influence of such factor as the expected duration of studies. The least impact of the factor is population migration. The increase in the level of education of human capital of Ukraine, the use of modern information and communication technologies and the implementation of the model "life-long learning" will positively influence the growth of social productivity, which will contribute to the growth of GDP of the country.

Innovation-investment model of human capital development in the conditions of globalization is presented in figure 2.

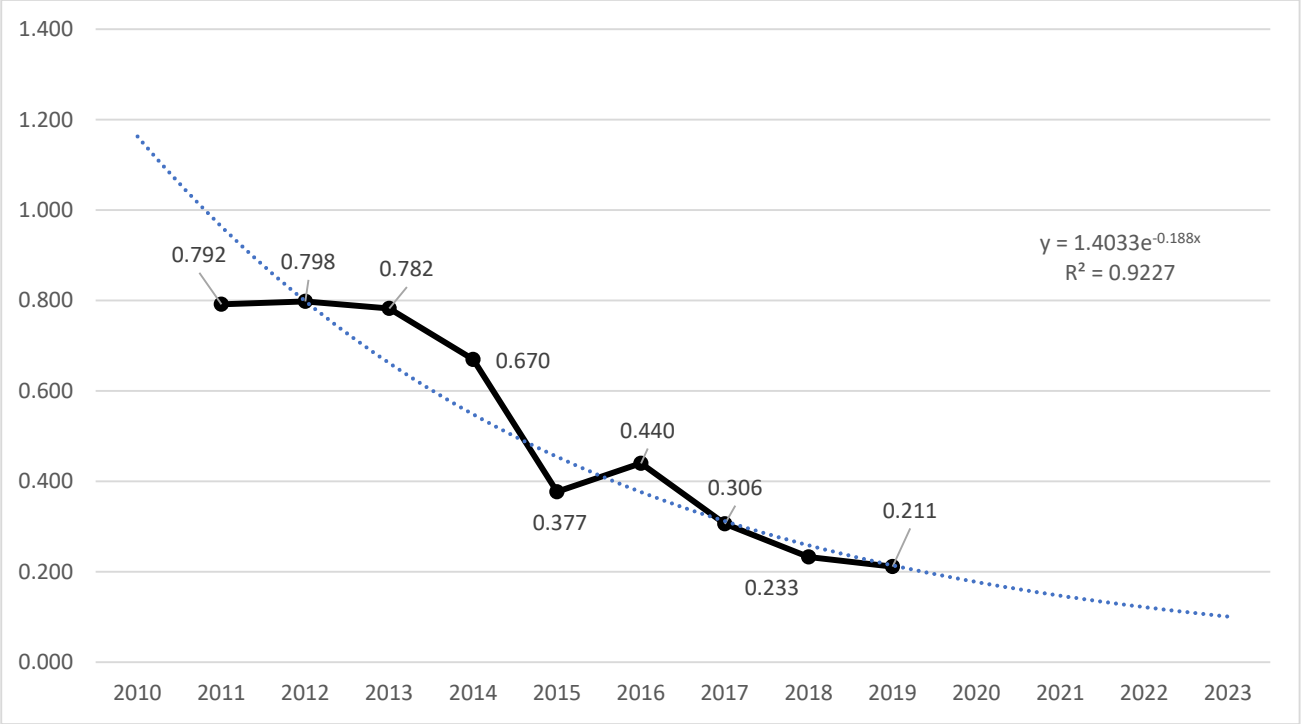

Fig. 1. Integral indicator of innovative development of human capital.

6 Areas of improving the quality of human capital

The formation of quality human capital is the main vector of the development of an innovative economy in the conditions of globalization. In our opinion, to overcome the problems of inefficient development of human capital and improve its quality, the state must take a set of measures that will contribute to the innovative development of the economy, namely:

- improving the legal framework towards ensuring the conditions for the effective reproduction and development of human capital;
- improvement of the state innovation policy and effective use of instruments of innovative development of human capital taking into account foreign experience;
- creation of appropriate institutional environment and adoption of programs for innovative development of human potential;
- creation of an effective mechanism for professional training of highly qualified specialists and raising their level of qualification taking into account the requirements of the modern labor market;
- formation of a new model of working life, based on the development of innovative forms and types of employment;
- enhancing the role of social dialogue and social partnership;
- improvement of the state migration policy to minimize the loss of human capital outflow;
- introduction of information and communication and social technologies, which will increase the level of development of human capital in post-industrial society;

From our point of view, the implementation of the proposed measures will help to increase the quality of human capital, which is a key resource for the development of an innovative economy and increase the competitiveness of the state.

7 Conclusion and perspectives

Thus, the innovative development of human capital is a

major factor in building a model of sustainable economic development in the context of globalization transformations, as it is formed through investment in human beings. The effectiveness of investment is determined by the level of development of productive abilities of the individual, capable of innovative work, creativity, creativity. The growth of the role of human capital in the conditions of sustainable development of the innovative economy necessitates the use of new approaches to its assessment, formation, and development. An important role in the reproduction of human capital is played by the state, which pursues regulatory policy using regulatory acts. The formation of an effective organizational and economic mechanism of state regulation of human capital development is a priority task that will create appropriate conditions for increasing the quality of human capital, its innovative potential, which will enhance the competitiveness of the national economy.

Further research will be to develop strategic directions and mechanisms for the development of innovative human capital, using the foreign experience of developed countries.

Fig. 2. Innovation and investment model of human capital development in the conditions of globalization.

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Methodical approach to the assessment of human capital level of machine-building enterprises

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Abstract. Human capital is a key factor in the success of any enterprise. Since human capital, like other types of capital, is prone to exposure to various types of risk and an important task of any enterprise is to assess the level of human capital. This paper proposes the author's approach to the formation of the structural components of human capital. Its structure included three sets of indicators that characterize educational, intellectual and physical capital. Also, a methodological approach is proposed to evaluate the human capital level of machine-building enterprises, which consists of three interrelated stages. The methodological approach is based on a point evaluation of the indicators included in the human capital structure based on the questionnaire (polling) of the personnel of the analyzed machine-building enterprises. The assessment of the level of human capital was carried out separately for two groups of workers. It is established that the total value of the integral index of human capital corresponds to the average level for all examined enterprises and ranges from 0,463 to 0,585. It has been found that the personnel at the machine-building enterprises have a great potential for development and a high propensity for change. The advantage of human capital assessment on the basis of its structural components is the ability to determine the optimal need for human resources and forecast the cost of supporting and developing human capital.

1 Introduction

The great competition that is observed in the domestic and foreign markets makes the managers of enterprises think about creating a tool that will increase the competitive advantage of the enterprise. One such tool is a human capital. In the papers [1, 2], it is stated that the assets of the enterprise based on knowledge are reflected in patents, brands, reputation of the enterprise and in the available human resources.

To date, a human capital is a key success factor for any enterprise and the most significant asset focused on an intellectual capital and a technology. The enterprises that effectively utilize the skills and the knowledge of their staff, are in the lead. Since the human capital, like other types of capital, is exposed to various types of risk, for example, the risk of expediency of investing in human resources, the risk of payback, an important task of any enterprise is the assessment of the human capital [3].

Many papers of foreign and domestic scientists are devoted to the issue of human capital assessment. The authors of [4] describe human capital in the form of skill databases based on a systematic approach. Also, R. Germon, P. Laclemence and B. Birregah [5] propose the matrix approach that enable to diagnose key threats to the development of the human capital of an enterprise. In the papers [6] analyzed the indicators of human capital assessment and defined the main criteria for evaluation and their impact on human capital. It also outlines the internal structure of human capital, which includes the funds of health, migration, motivation, intellectual capital and other funds. O. E. Kuzmin and A. Y. Shakhno [7, 8] used indicators to determine the index of human development and capital in assessing the country human capital. That is, macroeconomic indicators were used in the assessment. The study [9-11] proposed the human capital structure of the country, which consists of four groups, namely: economic indicators, demographics, education and science indicators. The author attributes to each of the proposed groups a system of indicators that characterize it. The scientist also noted that in the formed structure it is necessary to add indicators that would reflect the current state of qualitative components of human capital. Therefore, it is reasonable to develop existing methods and develop new modern approaches to human capital assessment. Human capital assessment on the basis of its structural components is extremely important, as it will determine the optimal need for human resources, predict the costs of maintaining and developing human capital in the short, medium and long term.

The level of development of the machine-building industry is characterized by the defense capability and scientific and technical state of development of the national economy of the country. Products in this field have a high level of science linkage and require a high level of knowledge, which in turn requires research into the issues of formation and assessment of human capital.

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Analyzing scientific paper on the study and structure of human capital, it was found that each scientist forms his own vision of this category. But the structural components of human capital include both production and professional characteristics of staff. However, in our opinion, that individual (personal) traits of a person that determine their ability to self-development are very important. Focusing on personal traits, we have developed the human capital structure of machine-building enterprises (Figure 1), which takes into account the main components that most scientists adhere to, namely ability, skills and health.

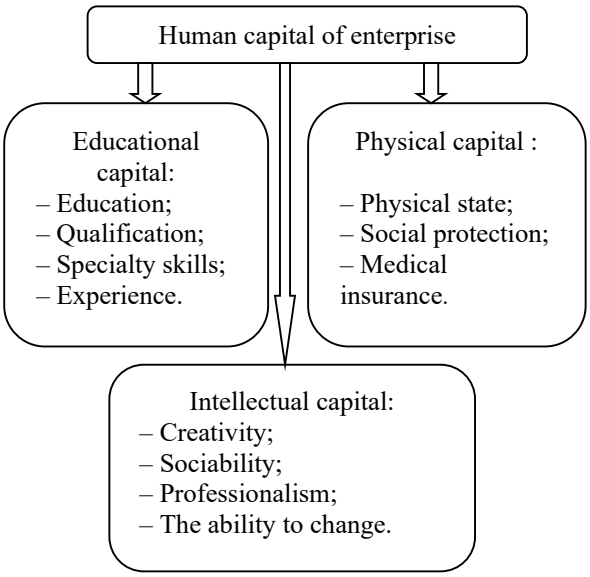

Fig. 1. Structural elements of human capital of the enterprise

Educational capital is formed on the basis of acquired knowledge, competences, education, qualifications. Experience is also an important component, reflecting the skills of a person as a result of a practical activity.

Intellectual capital characterizes the set of human mental abilities, forms the ability to absorb, analyze and process information, the propensity for creativity and the ability to generate innovative ideas.

Physical capital or physical health is one of the main components of human capital, because a physically healthy person will only develop professionally and generate new suggestions and ideas. The structural element "physical condition" analyzes the frequency of hospitalization at an enterprise, which characterizes the state of health of staff; "social protection" means the presence of a social package and social infrastructure in an enterprise; "health insurance" means the presence of an insurance pole. Also important is the psychological and moral health of the person. When the staff is positively tuned, the team creates comfortable conditions and thus forms an appropriate level of corporate culture. A sufficient level of corporate culture creates the conditions that facilitate the realization of new ideas and professional ambitions of the staff, which in turn contributes to the development of the enterprise as a whole.

2 Methodical approach to human capital assessment of the enterprise

On the basis of the formed human capital structure, the authors proposed a methodological approach to the human capital level of machine-building enterprises (Figure 2).

The proposed approach involves several major steps. The first stage is the examination, that is, the point evaluation of the level of educational, intellectual and physical capital on the basis of the questionnaire (polling) of employees. The second stage is the analysis of the information received, it involves establishing a link between the structural elements of each component of human capital and identifying the degree of consistency of expert assessments. The last third stage is an integrated assessment of the level of human capital. At this stage, the normalization of the input data, determination of the weight coefficients of the components of human capital and its integral evaluation.

On the basis of the proposed methodological approach, the human capital level of enterprises of the machine-building industry of Ukraine was evaluated. The polled enterprises were grouped into three groups: large, medium and small. A group of experts was hired to make polling and interviews with machine-building enterprises personnel. According to the results of the interviews, the experts rated the personnel on each structural element using a score scale from 1 to 7. The higher the score, the higher the level of the studied indicator [12].

Interviews were conducted separately for two groups of employees, namely: engineering and production staff. Expert assessments for each criterion were averaged for both the selected staff groups and for each of the examined enterprises.

According to the results of research of large machine-building enterprises, it is established that engineering and technical workers have a high level of education, creativity, communication skills and work experience. Average level of social security and health insurance. The production staff of JSC "Motor Sich" has the highest level of education, communication skills, specialty skills, professionalism and social protection of the companies under consideration. It should be also noted that the production staff of JSC "Motor Sich" and PJSC "ZAZ" are the most prone to changes and have a good level of physical condition.

Of all the (large) enterprises surveyed, PJSC "ZAZ" has the lowest ratings, which is not surprising since the company is in crisis. The volume of production and sale of products is very low, so in 2017 about 1% of the production capacity of the enterprise was involved in production.

Accordingly, expert assessments of the structural components of human capital in this enterprise are low.

According to the results of the examination of medium-sized enterprises, it was found that the highest level of education, among engineering and technical workers, was recorded at JSC "Zaporizhkran" which corresponds to a good level. Employees of JSC "Zaporizhkran" and LLC "ZAZOSNASTKA" have an

average qualification level. The employees of all the examined enterprises have a good level of skills, professionalism and work experience. Also, employees are prone and innovative and have a good level of physical condition. Employees of JSC "Zaporizhkran" were the most sociable and professional employees. The production staff of all the examined enterprises have a high level of education, high specialty skills and sufficient experience. At the following enterprises such as State Enterprise "ZDARZ" MiGremont "and LLC "ZAZOSNASTKA" the employees are prone to changes and have a good level of physical condition.

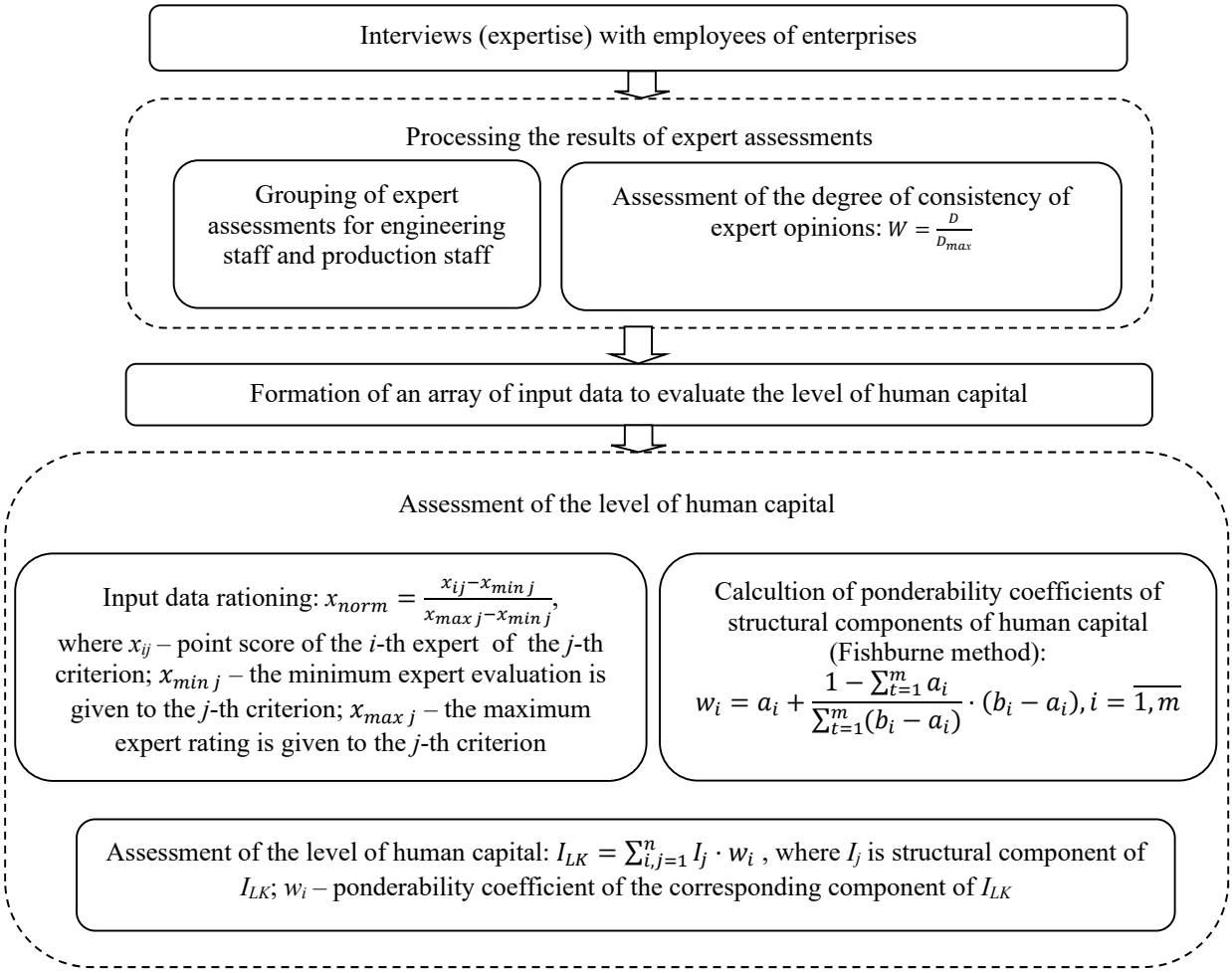

Fig. 2. Methodical approach to the human capital level of machine-building enterprises.

As a result of the expert evaluation of small enterprises, a high level of work experience, education and skills in the specialty has all engineering and technical staff. Analyzing the structural components of intellectual capital, it is clear that, according to the experts, the employees of these enterprises are characterized by a high level of creativity and communication skills. Engineering workers are prone to changes both in the professional sense and in the direction of forming the corporate culture. The physical condition is assessed to be good and social protection is therefore unsatisfactory and requires appropriate measures to be taken to increase the indicator. The production staff of small machine-building enterprises are characterized by a high level of work experience, professional skills, specialty skills and a tendency to change. Summing up the expert evaluation, we can conclude that the employees of these enterprises have high rates of human and intellectual capital, and the physical is slightly lower. Therefore, management should pay attention to this fact and develop a plan of measures to improve social protection and health insurance.

After grouping and averaging expert assessments, we will establish the link between the structural elements of each component of human capital. To do this, we calculate a nonparametric multiple correlation coefficient V , which is calculated by the formula [15]:

$$V = \sqrt{\frac{S}{(1/12)m^2 \cdot (d^3 - d)}}, \quad (1)$$

where d is the number of experts, m is the number of criteria,

S is the sum of squares of classes differences (deviations from the mean) and is determined as follows: $S = \sum |r_i - a| \cdot 2$, where a is the arithmetic mean of the sum of the classes.

Next, we determine the degree of concordance of expert opinions using the dispersion coefficient of concordance W (see Fig. 2). The results of the calculation of the correlation coefficients are given in Table 1.

The values of the obtained correlation coefficients are in the range from $0 \leq V, W \leq 1$. Therefore, we can conclude

that there is a significant relationship between the structural elements of human capital, since their values are in the range of $0.64 \le V \le 0.75$ for engineering staff and from $0.65 \le V \le 0.88$ for production personnel.

Based on the results of the calculations (Table 1), we can also conclude that the experts' estimates are sufficiently consistent, since the value of the coefficient of concordance is more than 0.5. In the study of production personnel, the consistency of experts is very high, since $W > 0.7$.

Table 1. Calculation of correlation coefficients.

Structural component of human capital	Engineering technicians (ET)		Production staff (PS)	
	V	*W*	*V*	*W*
Large enterprises				
Educational capital	0.641	0.788	0.734	0.712
Intellectual capital	0.755	0.678	0.882	0.790
Physical capital	0.647	0.687	0.657	0.793
Medium-sized enterprises				
Educational capital	0.641	0.788	0.734	0.712
Intellectual capital	0.715	0.687	0.882	0.790
Physical capital	0.647	0.688	0.657	0.793
Small enterprises				
Educational capital	0.693	0.759	0.832	0.599
Intellectual capital	0.585	0.879	0.627	0.634
Physical capital	0.620	0.727	0.609	0.873

According to Fig. 2, the next step is the normalization of the initial data and the determination of weighting factors. The indexation of indicators was carried out using the formula shown in Fig. 2. The weighting factor of each structural element will be determined using the Fishburne`s method [15]. This method is used when possible intervals of values of weighting factor are known. The expert team, during the examination, established possible limits for each of the indicators and structural components of human capital. The results of the calculation of the weighting factor for the indices of each structural component are given in Table 2.

Table 2. Ponderability coefficients of human capital components.

Indicators	Legend	Weighting factors, w_i
Structural elements of educational capital		
Education	x_1	0.215
Qualification	x_2	0.270
Specialty skills	x_3	0.277
Experience	x_4	0.238
		$\sum_{t=1}^{m} w_i = 1$
Structural elements of intellectual capital		
Creativity	x_5	0.210
Sociability	x_6	0.191
Professionalism	x_7	0.283
The ability to change	x_8	0.316
		$\sum_{t=1}^{m} w_i = 1$
Structural elements of physical capital		
Physical state	x_9	0.416
Social protection	x_{10}	0.296
Medical insurance	x_{11}	0.288
		$\sum_{t=1}^{m} w_i = 1$

Therefore, based on the calculations (Table 1) we can conclude that the most important components of educational capital are the skills in the specialty and qualification of employees. For the group of intellectual capital indicators, the most important is the ability to change, that is, the ability to develop and learn. As regards the weight of structural elements of physical capital, it is evident that the most important is the physical condition of employees. Of course, this component, in our opinion, is extremely important, because only a physically healthy worker will work with the maximum possible productivity and will strive for professional development.

The results of the averaging of the expert scoring with regard to the weighting factor for each group of enterprises are shown in Fig. 3–5.

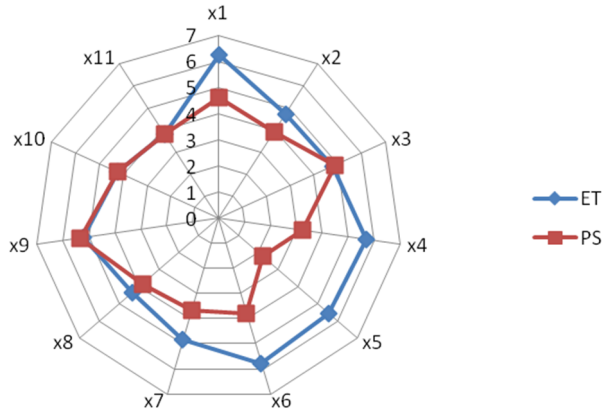

Fig. 3. Average point expert evaluation of the human capital components of large machine-building enterprises for 2018 (in conventional units).

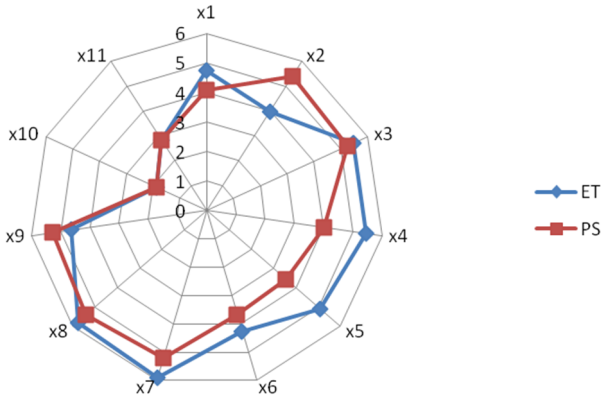

Fig. 4. Average point expert assessment of human capital components of medium-sized engineering enterprises for 2018 (in conventional units).

At the Fig. 3 we can see that engineering workers have 1.3 times higher education level, they are more creative and communicative with respect to production staff. This is due to the fact that the technical staff are more ambitious and prone to career advancement. It should be noted that production staff have a higher level of specialty skills (1.01 times) and have a better physical condition. The summed average point expert evaluation of the studied medium-sized machine-building enterprises (Fig. 4) indicates the high level of skills in the specialty, experience, creativity, professionalism and ability to change. Engineering workers are 1.43 times more creative and have more

experience (1.35 times) than manufacturing staff. Employees have good close to high level physical condition. The physical condition of production personnel is 1.13 times higher than at the engineering technicians. It is also worth noting that production personnel are more highly qualified (1.36 times) than engineering workers.

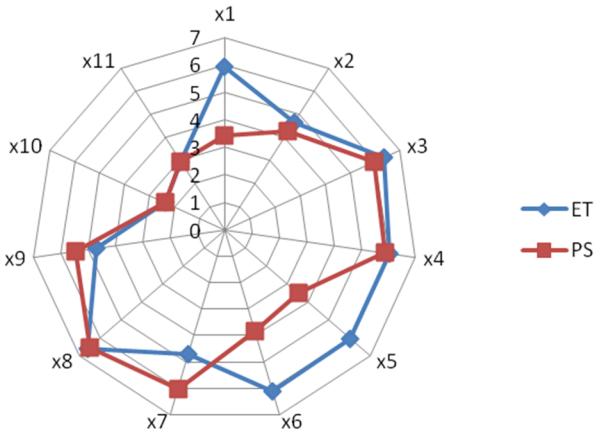

Fig. 5. The average point expert assessment of the human capital components of small machine-building enterprises for 2018 (in conventional units).

The weighted average point expert assessment of small enterprises indicates that the ability to change is paramount. This, in turn, indicates that the staff is ready for innovation, development and implementation of innovative ideas. Also, the Fig. 5 shows that almost all structural components of engineering and technical workers have higher grades than production personnel. The production personnel have higher average scores only on two indicators "professionalism" and "physical condition".

Weighting factors of the structural components of human capital were also determined using the Fishburne`s method. So weighting factors of educational capital is 0.331, of intellectual capital is 0.399, of physical capital is 0.270. Therefore, the most significant component of human capital is intellectual capital. Having determined weighting factors, we proceed to the next stage, namely, to estimate the level of human capital of engineering enterprises.

For large enterprises, the level of human capital is:

$$I^{V}_{LK(ITP)} = 0.619 \cdot 0.331 + 0.553 \cdot 0.399 + \\ +0.591 \cdot 0.270 = 0.585, \\ I^{V}_{LK(BIT)} = 0.595 \cdot 0.331 + 0.489 \cdot 0.399 + \\ +0.586 \cdot 0.270 = 0.550. \quad (2)$$

To explain the results of the level of the integral index of human capital and its structural components, we use the Harrington scale of desirability [15]. Therefore, the obtained level of integral index of human capital of large machine-building enterprises corresponds to a satisfactory level. But the level of human capital of engineering and technical workers is higher by 6.3% than the production personnel. The educational capital of engineering staff is 0.62 and indicates that this component is at a good level. All other values of the structural components of human capital range from 0.49 to 0.59, which corresponds to a satisfactory level.

For medium-sized enterprises, the level of human capital is:

$$I^{S}_{LK(ITP)} = 0.534 \cdot 0.331 + 0.412 \cdot 0.399 + \\ +0.470 \cdot 0.270 = 0.468, \\ I^{S}_{LK(BIT)} = 0.486 \cdot 0.331 + 0.475 \cdot 0.399 + \\ +0.418 \cdot 0.270 = 0.463. \quad (3)$$

The obtained values of the structural components of human capital according to Harrington's scale of desirability correspond to a satisfactory level. Educational capital of engineering and technical workers is 9.8% higher than production personnel. But the level of intellectual capital is higher for production personnel than for engineering and technical by 15.4%. As for physical capital, it is higher by 12.5% for engineering and technical workers. The overall value of the integral index of human capital of medium-sized machine-building enterprises corresponds to a satisfactory level, the level of human capital is higher by 1% for engineering and technical workers.

For small enterprises, the human capital level is:

$$I^{M}_{LK(ITP)} = 0.495 \cdot 0.331 + 0.561 \cdot 0.399 + \\ +0.488 \cdot 0.270 = 0.519, \\ I^{M}_{LK(BIT)} = 0.484 \cdot 0.331 + 0.515 \cdot 0.399 + \\ +0.455 \cdot 0.270 = 0.489. \quad (4)$$

The integral index of human capital of small machine-building enterprises corresponds to a satisfactory level. The human capital of engineering and technical personnel is 6.2% higher than the similar figure for production personnel. Educational, intellectual and physical capital of engineering and technical staff is also higher than that of production staff by 2.1%, 8.8% and 7.1% respectively. Therefore, we have determined the level of human capital of machine-building enterprises in terms of large, medium and small. It is established that the generalized value of the integral index of human capital corresponds to the average level for all investigated enterprises (Fig. 6).

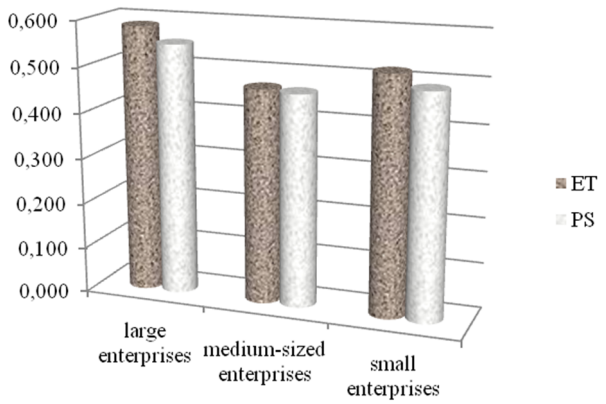

Fig. 6. The human capital level of machine-building enterprises of Zaporizhzhia region for 2018 (in conventional units).

The Fig. 6 shows that the lowest level of human capital is recorded in medium-sized enterprises. At large machine-building enterprises, the level of human capital of engineering and technical workers is higher by 25% compared to medium-sized enterprises. And in small enterprises the level of human capital is higher by 10.9% compared to the medium-sized enterprises. The level of human capital of production personnel in large enterprises is also higher: by 18.8% relative to medium-sized enterprises and by 12.6% relatively small enterprises. Large machine-building enterprises have the highest level of human capital and it makes in average of ILK = 0,568, which is 22% more than medium-sized enterprises and 12.7% more than small enterprises

3 Conclusions

Of great importance for the development of any industry is the staffing of the production process. Analyzing the general dynamics of the number of employees, there is an outflow of personnel potential both in industry as a whole and in mechanical engineering. This process is influenced by many different factors, and one of the main ones is the lack of material incentives for workers, which remains at a very low level. Therefore, to improve the situation with personnel, attention should be paid to the corporate culture of the enterprises of the machine-building complex, attracting highly qualified personnel by mobilizing financial resources to motivate and increase labor productivity in the future.

Improvement of the structure of human capital and its components, reflecting the basic individual (personality) features of person, which determine his ability to self-development is the scientific innovation of this paper. Suggested approach enables us to identify the strong points of the enterprise and the optimal need for human resources, to forecast the costs of supporting and developing human capital in the short, medium and long term. The proposed methodological approach to human capital assessment consists of three interrelated steps. The methodological approach is based on the expert evaluation of human capital components, namely the level of educational, intellectual and physical capital based on the questionnaire (polling) of employees. The approbation of the proposed approach was implemented to evaluate the human capital level of machine-building enterprises, which was grouped into three groups: large, medium and small.

The survey was conducted separately for two groups of workers, namely: engineering and technical workers, and industrial personnel. In accordance with the results of the calculations, it was found that the human capital of the researched enterprises, according to the Harrington scale, corresponds to a satisfactory level. Large enterprises have the highest level of human capital, and medium enterprises have the least. At large machine-building enterprises, the level of human capital of civil engineering workers is 25% higher in comparison with medium-sized enterprises. And in small enterprises, the level of human capital is higher by 10,9% compared with medium-sized enterprises. The level of human capital of industrial personnel in large enterprises is also higher: 18,8% relative to medium and 12,6% relative to small enterprises.

It should also be noted that the staff at the examined enterprises has a great potential for development and a high propensity for changes. Therefore, the research that is aimed at developing human capital based on the formation of a quality corporate culture is important. This direction of development will help improve the psychological climate in the team and increase the level of human capital.

The practical value of the paper is using the results of the research, which allow analyzing the level of human capital in the machine-building industry, determining the main aspects of the enterprise and formulating competitive advantages on their basis. Also, the results of the research provide an opportunity to justify the development strategy of the enterprise, taking into account elements of corporate culture.

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Tax policy for business entities under the conditions of association with the European Union: features and optimization directions

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Abstract. Under the conditions of EU association, one of the important for Georgia is to create such tax policy that shall be agreeable and settled with the economic systems of developed countries. The efficiency of the tax system depends on the optimal tax policy, according to which highly available and modern standard-oriented business environment is created. In 2017, the Parliament of Georgia passed the reform of profit tax that is aimed to free the business entities from profit tax during the reinvestment process. All the above mentioned maintains the topicality of ongoing reforms in Georgia. The goal of the research is to identify the impact of the new tax system on the Gross Domestic Product, the stream of investments, stimulation of business, and the period, after which the results of the reform will be favourable for the economic. There are various researches and scientific publications on the given issue. According to the study, the reform will produce a long-term macroeconomic effect that will mainly aim to favour small and middle scale businesses. Liberal tax approaches are advancing Georgia's investment attractiveness, reflecting an increase of investments. This work is based on Estonian experience presented in statistics and international studies. The information processed by experts and researchers helps us to evaluate the impact of this reform on Georgia.

1 Introduction

Nowadays, the economy as a whole body is composed of market mechanisms and state instruments complex approach to which demands highlighting fiscal policy – one of the highly significant policies of the country's financial politics. According to Cleomar Gomes da Silva & Flavio Villela Vieira [9], Fiscal policy has become an important economic tool in dealing with the consequences of the crisis. Tax policy ensures the efficient functioning of the state economic system. Any effective strategy or tactic of the state to stabilize the economy is a thoughtful policy reflected in sound tax law, a fair system of tax administration. It is essential to note that it is impossible to establish effective market relations without a well-functioning tax system. Theoretically and practically understood, scientifically justified taxes can have a positive influence on economic activity and production capacity. The effectiveness of the tax system is linked to optimal tax policy [4, 6, 10-12, 16, 19, 23, 25-27], which creates the most optimal, affordable and up-to-date business environment. Besides, optimization shall mean solving of two important tasks, namely: maximum mobilization of budget revenues and taking into consideration paying capacity of tax payers in imposing of tax rates. Besides, it should be also taken into account that even in condition of full admissibility of tax burden, taxes may be seriously distorted. Topicality of research of income taxation problems is also conditioned with sharp manifestation of negative trends of effect of tax policy on the pace of economic activity [1].

The purpose of this paper is to discuss the theoretical and practical aspects of the Estonian state as an "Economic Miracle" and to represent Georgian perspectives of the Estonian model and its actual results. The following tasks are set to achieve the goal:

- Determining priorities and characteristics of the "Estonian" model;
- Evaluation of the effectiveness of the "Estonian" tax mechanisms in the economy of Estonia;
- Presentation of tax environment and tax stimulation mechanisms that exist in Georgia;
- Estimation of the "Estonian" model impact on the performance of business entities.

The purpose of this study is to determine the impact of tax policy on business activities and evaluate its development directions.

The methodological basis of the research. The methodological basis of the research is legal and economic aspects of tax policy. This paper uses works by the local and foreign authors, legislative base, statistical information and other research materials. The information displayed in the work is formed on the database of the National Statistics Office of Georgia, Ministry of Finance, Ministry of Economy and

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Sustainable Development of Georgia and other structures.

2 Literature review

The work uses publications from local and foreign authors, legal bases, articles, scientific research, statistical information and other research materials. Out of those, it is important to analyse the studies and opinions of experts on the Estonian model, such as: Masso, Merikull & Vahter's [21] research shows that corporate tax reform in Estonian companies has increased the number of liquid assets and reduced debt financing. The study also confirms the positive effects on investment and labour productivity. According to the authors, such development of events have contributed to the sustainability of firms, making it easier for Estonian companies to handle the 2008 financial crisis. Bellak & Leibrecht [7] studies show that it is improbable to correlate the increased investments in Estonia only to corporate income tax reform. Aforementioned may be due to the factors such as labour market, market size and other related issues etc.

According to the authors [20, 22, 24] – a stable business environment, a low levels of bureaucracy and corruption, protection of private property, the rule of law, solid guarantees of investment protection and a consistent economic policy of the state have guaranteed Estonia's "economic miracle".

Within the project, financed by the USAID, economists [22, 24] have developed a general equilibrium model of neoclassical economic growth, according to which:

- Reform has a supportive effect on investment. The stock capital will grow by 3.23% in 1.5 years. The reform will lead to an increase in net investments;
- Total private consumption will rise by 0.85% in 1.5 years;
- The reform will increase the government's annual budget deficit by a maximum of 3%. However, a 1% growth in income tax and a 1.25% VAT increase would eliminate the deficit.

The result of the reform will be visible in about 1.5 years.

3 Influence of tax policy on activities of business entities and directions for optimization

3.1 Tax mechanisms for regulating the activities of business entities

One of the main tools of state regulation of business activities is tax policy, which in turn is a system of planned actions of the state based on economic, legal and controlling activities in taxation.

The world experience shows (for example, the Baltic States, Turkey) that economic development is always linked to structural changes in the economy. It is a process that involves the distribution of economic activities between agriculture, services and industry, followed by the modernization of the economy, the increase in employment and labour productivity. The private sector is the main navigator of structural changes in the economy.

At the modern stage of development, Georgia aims to blend into the world economic climate, and it can be achieved by harmonizing the business environment. The tax policy represents an important part of economic integration, which in turn impacts the production sector, competition, production and sale. In combination with the mentioned, taxes affect the social and political situation in the country.

In the framework of the Association Agreement between Georgia and the European Union, fiscal legislation has been brought closer to EU legislation in our country. Tax administration was simplified and tax sanctions were optimized. The limitation period defined by the Tax Code has been gradually reduced in the country. Most importantly, the legal relationship between the state and business was based on the principles of equality.

According to the international indexes, Georgia is already in the leading position: as reported by the World Bank's Doing Business 2019 release, Georgia ranks 6th out of 190 countries in terms of ease of doing business [13]. In this view, Georgia stands out in the European and Central Asian region as a state that has taken important steps towards efficient administration.

Georgia holds the leading position in terms of low tax burden following Qatar, the United Arab Emirates and Hong Kong (Fig. 1) [5].

At present, according to the tax legislation of Georgia 6 taxes are in place instead of 21 (Table 1).

Table 1. Current tax rates in Georgia

Tax	Rate
Profit	15%
Income	20%
VAT	18%
Import	0 %, 5%, 12%
Property	<1%
Dividend	5%

Source: Ministry of Finance of Georgia [29]

Specific tax regimes (Table 2) are in place, for:

- Individuals with microbusiness status;
- Entrepreneur Individuals with small business status;
- Individuals with fixed taxpayer status.

Individuals with a particular status enjoy certain benefits under the Georgian legislation that allow them to develop their business activity. Specific features and advantages of the specific taxation are as follows.

In Georgia, there are certain types of tax privileges to stimulate business development and draw additional foreign investments to a particular geographic area. In 2015, to stimulate the development of mountain regions, a law on the development of such regions was developed. The initiative is aimed at individuals and

legal entities operating in settlements with a high-mountain status.

Advantages:

1. An entrepreneur with a high mountain status is free from the income tax for 10 years after receiving the status.
2. An entrepreneur with a high mountain status is free from the profit tax for 10 years after receiving the status.
3. Property owned by a highland-status enterprise is exempt from the property tax for 10 years.

Business, registered in the free industrial zone, is:

1. Exempt from all taxes except income tax (remuneration of hired workers).
2. Foreign goods introduced into the zone are exempt from the value-added tax.
3. In case of conducting certain activities, it is freed from the obligation to obtain a license/permit or uses a simplified procedure for obtaining them.
4. In the case of supplying (import) the products produced within the zone into other territories of Georgia, the import tax shall be cleared.

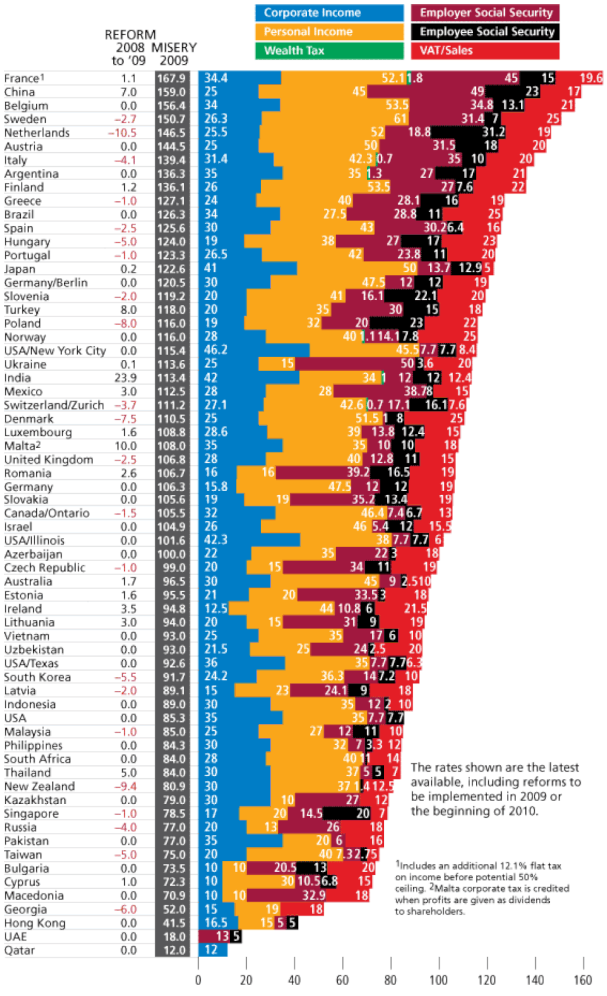

Fig. 1. Tax Misery and Reform Index.

Despite implemented reforms, the rating of the countries according to Global Competitiveness index (GCI) is as follows: Switzerland (5,81); Estonia (4,78); Lithuania (4,60); Azerbaijan (4,55); Russia (4,51); Latvia (4,45); Turkey (4,39); Georgia (4,32); Armenia (4,07); Ukraine (4,00) [2]. As we see, Georgia cannot be proud of the absolute deficit of free competition, while the constant concern of companies in developed countries is exactly the competition. The catalyst for generating a competitive environment is the development of business entities that encourage the distribution of modern standards and lifestyles. This, in turn, limits the growth of large city agglomeration and forms a solid foundation for the advancement of social-economic development.

Table 2. Specific tax regimes: conditions and advantages.

	Conditions	Advantages
Micro business – The status applies to individuals who independently conduct economic activity:	Their total gross income does not exceed 30,000 GEL during the calendar year; They do not have employees; Their commodity supply (materials, finished products, unfinished production) does not exceed 45,000 GEL; They are not VAT payers	Individuals with Micro business status are exempt from the income tax; Individuals with a Micro business status are exempt from the use of a cash register.
Small business- The status is granted to entrepreneurs who:	Their total gross income does not exceed 500,000 GEL during the calendar year; Their commodity supply does not exceed 150,000 GEL.	Chargeable income of an individual with a small business status is taxed at 1%; The income of an individual with the above status is taxed at 3% only if the entrepreneur has the opportunity to provide documents for 60% of the expenses (other than salary); The opportunity of simplified tax accounting.

Source: composed by the author based on tax code data

USAID research indicates that changes are not always clear and easy to understand. This can be the basis for unintentional offence and fines. In conclusion, it can be stated that despite the internationally recognized liberal tax policy, companies' view towards the country's tax legislation is more negative than positive. This is due to frequent changes to the Tax Code and vague records, as well as a high tax pressure.

In this situation, minor changes in certain segments of the economy, including in the tax system, the

fragmented transformation of parts of the economy do not lead to the desired outcomes [2]. According to the economic theory of supply with the view of resolving the problem of country's economy tax decrease is necessary. With low tax rates business owners have opportunity to accumulate, which provides complete utilization of business potential and increase of GDP of the country [3].

3.2 Taxation measures for business entities in Estonia and its efficiency

One of the traits of the Estonian model is the simplicity of tax administration and tax legislation, which simplifies certain types of business procedures. Tax administration is implemented by a risk management program, rigidly controlling tax avoidance cases. The simplicity of the tax declaration directly impacts the number of tax penalties and fines, which also significantly lessens the cost of tax administration for both the state and the business.

A stable business environment, little bureaucracy, low levels of corruption, protection of private property, the rule of law, trustworthy guarantees of investment security and a consistent economic policy of the state have ensured Estonia's "Economic Miracle" [8, 17, 22, 24].

The business climate in Estonia is distinguished by a free trade system. Estonia has a high credit rating in the region. There are four free trade zones in the country. Estonia is ranked 7th out of 180 countries in the 2018 Index of Economic Freedom by the Wall Street Journal and the Heritage Foundation (table 3).

Table 3. Index of economic freedom of the world – 2018.

I	**Hong Kong**
II	Singapore
III	New Zealand
IV	Switzerland
V	Australia
VI	Ireland
VII	Estonia
VIII	Great Britain
IX	Canada
X	United Arabian Emirates

Source: Index of economic freedom, 2018 [8, 15]

By the 2018 year data, Estonia has broken the record for world startups (Fig. 2). The progress of startups in Estonia is driven by many factors. The most important ones are tax environment, simple registration of companies, IT sector state programs and stable economic environment.

It is important to note that Estonia designates substantial funds from the budget. According to 2018 statistics, Estonia has invested 328 million Euros in startups, which is the highest financial figure compared to other years.

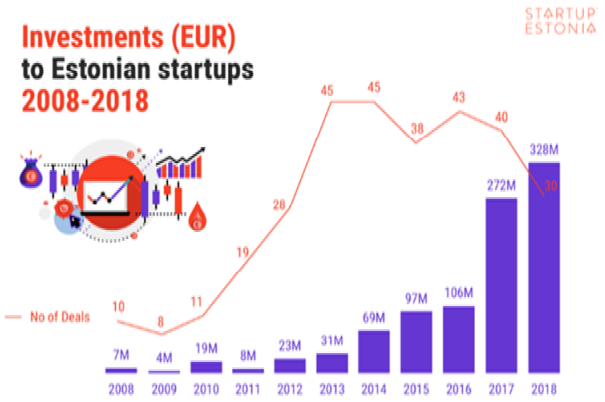

Fig. 2. Startup investments in Estonia (EUR) – 2018
Source: startupestonia [28]

It is also remarkable that the increase in the number of employees in startups is reflected in the taxes paid by employees. As of 2018, this figure is 46 million euros, in 2017 – 36 million euros and 2016 – 27 million euros. These numbers show that annual growth between each year equals to 30%.

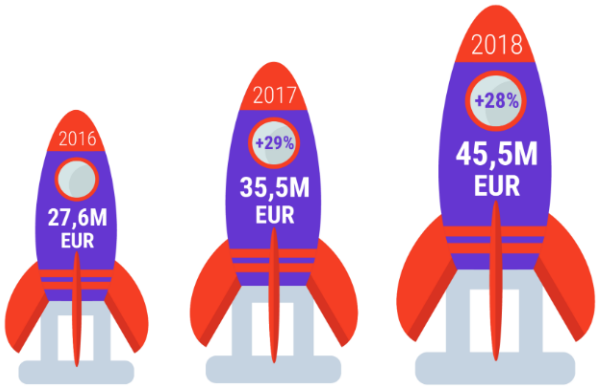

Fig. 3. Employee paid taxes for Estonian startups – 2018
Source: startupestonia [28]

3.3 Comparison of business environment of Estonia and Georgia and tax mechanism harmonization matters

The so-called "Estonian" model of profit tax has been operating in the Georgian tax system since January 1, 2017, intending to promote economic growth based on business reinvestment opportunities. The peculiarity of the Estonian model is that the company's profit tax is suspended until the profit is distributed, enabling the business entity to conserve a certain amount of financial resources and to utilise these funds for reinvestment. The Estonian model is mainly focused on the rational allocation of financial results.

The Estonian model in Georgia provides:

1. Business opportunity progress;
2. Creating an attractive business atmosphere;
3. Promotion of capital growth;
4. Increase the company's liquidity;
5. Accelerate economic growth.

However, any change in the level of reinvestment may result in a reduction in tax revenue. Increasing tax

revenues in this field can be achieved through improved tax administration or increased tax rates. Foretelling the effects of tax administration is difficult, unlike rate rises, which allow us to more or less analyze them. In the case of Georgia, raising rates is prohibited by the Economic Freedom Act. However, by the same act "the Government of Georgia has the right to request a temporary increase of taxes for a period not exceeding three years. In this case, the referendum is not held (Organic Law of Georgia on Economic Freedom).

In general, if we compare the investment part of Estonia and Georgia according to the so-called Benchmark Georgia, the investment business environment is as follows:

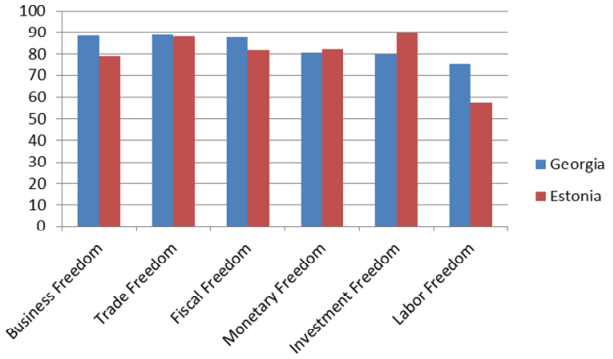

Fig. 4. Investment environment, Georgia/Estonia
Source: Compiled by the authors based on data from the Invest in Georgia [18]

As we can see from figure 4, according to the Freedom of Doing Business, Georgia scores 9.5 points more than Estonia. Georgia is also in the leading position with the indexes of trade, fiscal, legal freedom.

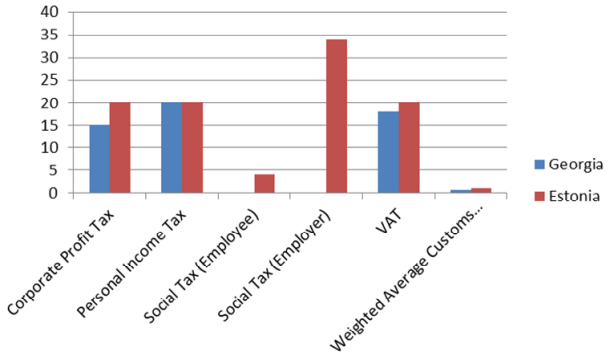

Fig. 5. Taxes %, Georgia / Estonia
Source: Compiled by the authors based on data from the Invest in Georgia [18]

According to figure 5, related to the taxes, corporate profit tax, social tax and VAT in Estonia are higher than in Georgia.

According to the Tax Code of Georgia, the object of taxation with the Estonian model of income tax is:
– Distributed earnings (including price differences);
– Non-economic expenses and payments;
– Complimentary supply (e.g supply of goods, services and funds);
– Representative expenditure above the limit.

By the "Estonian" model, a taxpayer is a resident enterprise as defined by the Tax Code, as well as a non-resident one operating in Georgia with a permanent enterprise and/or receiving income from a Georgian source.

The profit tax rate is 15%. Profit tax-deductible amount is obtained by dividing the number of payouts/expenses divided by 0.85.

By the "Estonian" model, the profit tax calculation period is one calendar month. The profit tax monthly declaration is submitted to the taxation organ by the taxpayer (electronic form), no later than the 15th day of the following month of the reporting month and in the same period, a profit tax shall be paid.

According to the Estonian model, taxpayers are all the enterprises, except:
– Financial institutions;
– Systemic-electronic form of the slots;
– Companies defined by law on "Oil and Gas";
– A non-resident enterprise whose income from a source in Georgia does not belong to its permanent establishment in the country;
– An individual entrepreneur;
– Individuals with microbusiness status;
– Individuals with fixed taxpayer status;
– Organisations (including: LEPL, N(N)LE, charity organisations).

The Estonian model eliminates double taxation. Under the model, an enterprise has the right to account for the amounts of tax accumulated and paid on the distribution of net profits received in given years (2008-2016), provided that profits are distributed over that period.

To avoid double taxation, on June 7, 2017, within the framework of the OECD Week, Georgia signed Multilateral Convention to Implement Tax Treaty Related Measures to Prevent Base Erosion and Profit Shifting (MLI).

The main purpose of the treaty "Avoidance of Double Taxation and the Prevention of Fiscal Evasion" is to promote deeper economic cooperation and attract investments. The texts of the agreements concluded by Georgia are based on the Organization for Economic Co-operation and Development (OECD) model and set out the principles of taxation between countries.

In particular, income collected from activities carried on by legal entities and individual entrepreneurs in the other country shall be taxable in the country in which it was obtained or in the residence state. In the case of taxation in the income source country, the resident country undertakes the responsibility, to avoid double taxation, to consider the tax paid in the source state. The main objective of the agreement is also to avoid tax evasion, which is achieved by the introduction of international standards for the exchange of information for tax purposes.

Nowadays, the treaty "Avoidance of Double Taxation and the Prevention of Fiscal Evasion" is in force in 55 countries [29].

In a situation where access to cheap financial resources for small and medium-sized enterprises in

Georgia is complicated, the untaxed undistributed profit, which results in more resources available for reinvestment, are of particular importance. "Research and development", which requires additional expenses from companies, is exactly what most businesses in Georgia need, and the Estonian model encourages exactly that kind of reinvestment. It is almost impossible for Georgian businesses to establish a place on the EU market without additional financial expenses. The undistributed profit of potential exporters in the EU market may play a significant role in raising that export potential.

"The results of a study by Alexander Lungvist (New York University) and Mikhail Smoliansky (Federal Reserve System) support the assumption that profit tax cuts can have notable positive economic outcomes only when such fiscal policies are implemented in times of economic recession. Researchers also suggest that large scale profit tax cuts are needed to accomplish real social-economic benefits" [14].

It should also be remarked that Estonia's "economic miracle" was not linked to only one specific tax reform, but also to complex changes that ultimately drove to effective results and economic growth. Concerning Georgia, no complex policy has been fulfilled, and therefore, sharing one particular reform in a country where the tax culture is distinct from Estonia, in our opinion will not produce any long-term positive results.

The tax policy implemented by the state needs to support economic growth and development, that is why on the one hand, it is important for the country to properly and rationally-design tax system and the actions that will not harm output and investments, on the other hand, the government should carry out their functions and the tasks required for the implementation of activities and programs using funds accumulated through taxes. Furthermore, the tax policy should be structured so that the increase in budget revenues does not suppress the activities of private entrepreneurship. It should ensure the fairness of economic conditions and the development of nominal operating conditions of the economy. Optimal tax policy might well lead to the growth and improvement of the economy to a balanced budget and not to an artificially balanced budget.

4 Conclusions and recommendations

Corporate profit tax reform in Estonia, that is introducing Estonian model for profit tax at the legislative level is connected to the complex state reforms, in which we include legislative changes, currency reforms, the effective tax administration, the creation of a private sector-friendly environment, and other reforms which created the evenly profitable business climate. If we assess the situation in Georgia, we will see that no such steps have been taken in our country. Sharing the so-called Estonian model alone will not have the economic effect it had in Estonia, as Estonia's tax policy was highly incorporating, unlike Georgia's.

In addition to all this, the tax legislation in Georgia is undergoing constant changes, which creates an unstable atmosphere for business entities. In Estonia, the efficiency of corporate income tax reform was helped by a steady macroeconomic environment, which is not a stable process for Georgia. The effective functioning of the tax system is influenced by a tax culture, which is low in Georgia, unlike Estonia, where business entities are aware that they must participate in the formation of budget revenues. The results of the reform are more effective in Estonia than in Georgia, as the reduction of tax pressure in Estonia before 2000 allowed companies to reinvest profits. As for Georgia, the tax policy was already liberal before the profit tax reform, unlike Estonia.

The stimulus programs in Estonia are diverse, in particular, the Start-up Estonian program, where the budget allocates substantial funds. As for Georgia, the Startup – Georgia program is also progressing, which is a strengthening factor for new businesses. Before-mentioned programs play an important role in the evolution of business activities.

Finally, to compensate for the loss of budget funds owing to profit tax reform, the state should focus on effective tax administration measures, targeted use of budget revenues and budget expenditure reductions.

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Management of the national economy productivity: the experience of European integration

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Abstract. Productivity and economic growth are key factors to maintain and improve the competitiveness of nations in the global market. The paper analyzes the impact of changes in labour productivity and its effect on the nation's global competitiveness. The research focuses on the European Union countries and Ukraine that experienced the most severe crisis and afterwards the most rapid recovery in the post-crisis period. At the national level, sufficient productivity dynamics are supported by high levels of market competition, broad investment opportunities, and investment promotion. At the same time, the constant acceleration of the action and volatility of exogenous factors of economic development, qualitative transformations of endogenous factors determine the relevance of constant monitoring of the state of productivity and forecasting it for the medium and long-term periods.

1 Introduction

The key problem of the economy in recent decades has shifted from a lack of natural development resources to a lack of knowledge to further human empowerment. In productivity theories, there is increased attention to the problem of knowledge as the basis for economic growth and productivity improvement, namely, the creation of knowledge, its transfer, and perception, Charles I. Jones, Paul M. Romer [1], Roberto Cardarelli, Lusine Lusinyan [2], Ulrich Kohli [3], Kirk Hamilton, Esther Naikal, Glenn-Marie Lange [4], J. Remes, J. Manyika, J. Bughin [5], Jungsuk Kim & Jungsoo Park [6], A. Kaasa [7] et al.

The reduction of productivity growth rates in the group of developed countries from 2.4% in 2000-2004 to 0.5% in 2010-2014 became a significant problem and actualized the scientific task of searching for new factors of economic growth [8]. The study found that at the turn of the first-second decade of this century, the information and communication technologies gradually lost their reinforcing impulses; the restructuring of domestic operations and global supply chains were completed. The consequences of the global financial and economic crisis had a significant negative impact on productivity dynamics. This was manifested in the growth of negative expectations, reduction of financial and investment flows. Finally, the promising trend of digitalization of the economy at this stage has not yet produced a significant positive effect but has increased the transition costs.

2 Related literature

Development within the framework of the integration association contributes to the productivity increase of national economies, attracting the latest innovative growth factors to the fast action. The study of the experience of such growth of the Member States of the European Union is useful for Ukraine and can be carried out by modelling economic development and productivity on the example of the Czech Republic, Hungary, Estonia, Lithuania, Latvia, Poland and Slovakia as the most effective, compared with Ukraine. In this case, we propose to use the algorithm shown in Fig. 1, using the correlation-regression and cluster analyses. The neoclassical approach in the study and forecasting of economic growth and productivity ([1-7] etc.) is based on the production function, the components of which are capital, labour, the total productivity of production factors, etc. depending on the assumptions made about the type of the production function.

The most common methods of productivity assessing determine the amount of GDP created per hour of working time; the volume of output per unit of productive capital; the definition of multifactor productivity, which measures the contribution to the economic growth of other factors that are technological, organizational, and innovative.

The problem of the interdependence of competitiveness and productivity of national economies has been sufficiently studied in the scientific literature. It has been established that the support of competitiveness at the level of national policy contributes to the increase of aggregate productivity and determines the prospects for economic growth. To increase productivity at the micro level the business maximizes its efficiency through the introduction of an innovative product, management technologies, the creation of new products to meet

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consumer demand.

Charles I. Jones and Paul M. Romer [1] founded that the contemporary model of economic growth and productivity was determined by four basic components, ideas, institutions, population, and human capital, while the leading role gave to the human capital. Similar conclusions made by Ulrich Kohli [3]: based on the example of the US economy, scientist founded that the modern dynamics of TFP is mainly explained by labour. In the research of US TFP Dynamics made by Roberto Cardarelli and Lusine Lusinyan [2] suggested that policies that promote investment in human capital and innovation may boost aggregate TFP growth.

Kirk Hamilton, Esther Naikal, and Glenn-Marie Lange [4] in the research of productivity growth factors in developing countries, shown the loss of natural resource efficiency and the growing role of innovation and human capital.

Jungsuk Kim and Jungsoo Park [6] grounded that the value of the technological component of productivity growth is growing in the transition process from the middle to high levels of development. This component is critically important in overcoming the challenges that middle-income countries face when they need to transition to a high-income group.

The results of A. Kaasa [7] study proved that a safe and stable environment where people and firms trust institutions, feel secure and participate in social processes is hugely significant for high productivity. In an inter-sectoral endogenous innovation model, T. Harada [8] proved the crucial role of the relation-specific investment for the evolution of the industry structure. The scientist grounded that productivity growth will be driven by economic policy measures.

J. Lopez-Rodriguez and D. Martinez-Lopez [9] studied non-R&D innovation activities account and grounded the significant proportion of innovation efforts carried out across very heterogeneous economies in Europe. An extended macro-theoretical growth model allows taking into account these non-standard factors.

The analysis of structural transformations of the Ukrainian economy is carried out in a scientific report "Structural Transformations in the Ukrainian Economy: Dynamics, Contradictions and Impact on Economic Development" (2015) [10]. The results allow substantiating the necessity to deal with technological, institutional, reproductive constraints for accelerating the impact of the latest drivers of productivity growth.

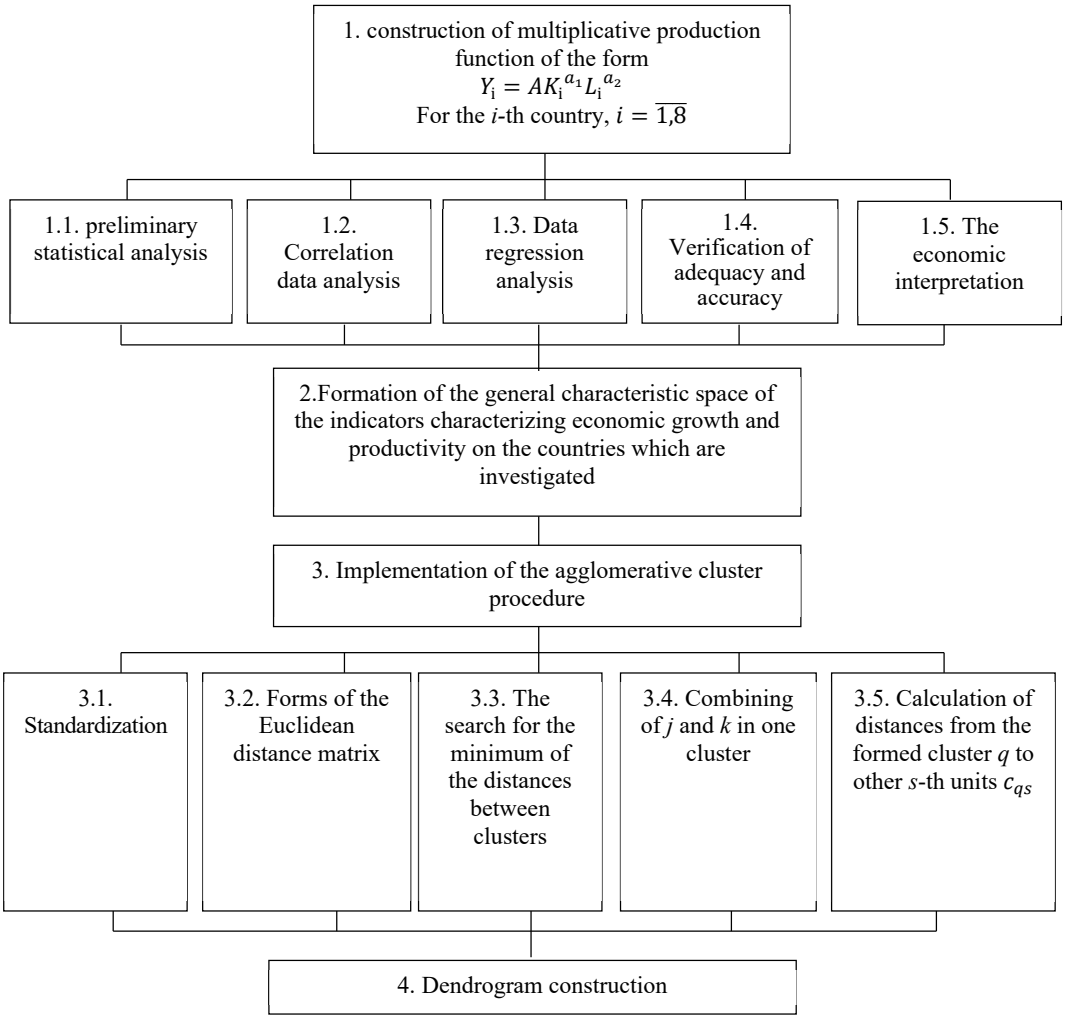

Fig. 1. Procedure for economic development modelling and productivity of countries.

A. Filipenko [11] noted that the Ukrainian economy characterized by immaturity of the institutional structure, so indirect factors of productivity are also important for it. These factors are the support of civil liberties, participation in civil affairs, support of the interpersonal trust.

Recently, the works [1-14; 16-17] discuss the issues of justification of productivity indicators in the economy as a whole and by types of the economic activity based on the multifactor productivity model KLEMS, which combines indicators of the type "capital (*K*), labour (*L*) – energy (*E*) – materials (*M*) – services (*S)*".

Since the early 2000s, the EU-KLEMS consortium has been established in the EU to implement this model. Its main task is to create a database of comparable statistical indicators at the industry level and to conduct a series of studies on the relationship between the growth of labour force skills, technological progress, and innovation, on the one hand, and productivity, on the other. The database contains relevant indicators at the level of 63 industries of the EU Member States, as well as the United States, Japan and Canada and several countries in Asia and Latin America. According to N. V. Stativka [13], the EU-KLEMS project investigates the period of 1970-1990. So, scientists from other countries face such disputable issues:
1) lack of access to the information of the created database;
2) other sources of official statistical information do not provide full or partial data on productivity factors for different countries in the retrospective period;
3) partial absence of harmonized indicators of different countries, which are not included in the KLEMS databases, for generalization and international comparisons.

3 The purpose of the research

This work aims to analyse the impact of changes in labour productivity and its effect on the nation's global competitiveness based on the experience of EU Central European countries and Ukraine.

The key task for improving resource efficiency as well as the quality of human social capital and the institutional environment is enhancing the productivity of the economy. The productivity's estimating through the TFP model allows assessing the contribution of key factors – labour and capital to the national wealth. Ukraine needs a balanced and constructive policy of productivity-improving on the reform pathways. Ukraine has made significant progress in opening up the economy, participating in global trade, manufacturing, and investment processes since 1991. However, the results of the openness policy didn't reflect in the improvement of living standards. Hence, it is important to explore the successful reform experience in European countries that have become EU members and have steadily increased productivity. This will help to identify directions for improving Ukraine's government policy to enhance its international competitiveness.

4 Results

The highest levels of socio-economic development are found in the countries with open economies and they actively compete in the world economic space. The international competitiveness of national economies depends on their productivity.

Productivity is usually defined as the ratio between the number of resources involved and the total result. That is, the efficient use of development resources is being under discussion. Long-term trends in productivity give a fairly accurate picture of the prospects for the economic growth of countries, changes in the situation in the industry markets, etc.

To study the indicators of economic growth and productivity of 7 countries that since 2004 have become members of the EU (Czech Republic, Estonia, Latvia, Lithuania, Poland, Slovakia, Hungary) and Ukraine as an information base of the study for 1991–2017, the following statistics [15] were used:

1. GDP (constant prices 2010, USD) – *Y*;
2. Gross fixed capital formation at constant prices in 2010, USD (GDP (constant 2010, USD)) – *K*;
3. Employed persons in thousands – *L*;

The whole data set was divided into 2 periods:

1. 1991-2003, that is, the period before the entrance of the 7 studied countries to the EU;
2. 2004-2017 – the period during which it is possible to allocate consequences for economic development and productivity of these 7 countries after their entrance to the EU and Ukraine, table 1.

The results of the calculations made it possible to form a significant body of information, summarizing which we can draw the following conclusions:

The period of 1991-2003. Only Latvia has an extensive type of GDP growth, with its GDP growing faster than it does on the average with capital and labour. All other countries are characterized by the intensive growth in production, which also increases more slowly than the model factors.

The period of 2003-2017. After the entry of 7 countries under the research into the EU, there was a significant change in the features of GDP growth. In particular, 5 countries (Czech Republic, Estonia, Hungary and Slovakia, and Ukraine) are characterized by an extensive (Fund-intensive) growth in output, and in 3 of these countries, the GDP growth is faster than the average growth of capital and labour. These countries include the Czech Republic, Hungary, and Slovakia. It should be noted that the constructed multiplicative model of the production function for Latvia gave statistically insignificant characteristics and was inadequate. Therefore, it was not included in the overall analysis of productivity and economic development of countries in the study period from 2004 to 2017, and therefore, there is no possibility to compare changes in Latvia before and after the entrance to the EU.

As has been noted earlier, the simulation results allowed us to form a feature space, which can be summarized in the table 1. It should be noted that the economic development of the studied countries is characterized by a significant number of indicators, which

can include the average growth rates of GDP, gross fixed capital formation, number of employed persons, as well as the results obtained by constructing a multiplicative production function (Fig. 1). The main ones are the coefficient of determination, the average return on capital, the marginal productivity of the main capital, as well as the private elasticity of output by capital and labour.

Table 1. Generalized indicators of economic development and productivity of countries for 2 periods (according to the Eurostat data [15]).

Countries	**Czech Republic**		**Estonia**		**Hungary**		**Latvia**		**Lithuania**		**Poland**		**Slovak Republic (Slovakia)**		**Ukraine**	
Period (1 – 1991-2003, 2 – 2003-2017) / Indicators	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
The average GDP growth rate	2.13	2.61	6.28	2.47	2.31	1.46	5.96	-	5.88	2.96	4.29	3.83	4.07	3.82	-4.22	0.07
The average growth rate of gross fixed capital formation	5.58	2.29	14.13	1.88	4.69	1.06	15.99	-	11.02	3	6.3	4.99	2.07	2.93	-9.01	-1.64
The average growth rate of employed persons	-0.2	0.76	-0.66	0.53	-1.04	0.57	6.5	-	-0.49	-0.31	-0.39	1.3	-0.36	1.06	-1.77	-1.68
Coefficient of determination	0.97	0.91	0.97	0.51	0.96	0.72	0.91	-	0.92	0.83	0.99	0.87	0.87	0.88	0.98	0.58
The average return on investment	3.91	3.73	4.7	3.71	4.96	4.63	5.58	-	5.98	5	5.9	4.97	3.56	4.27	4.07	4.94
The marginal productivity of fixed capital	1.32	0.49	2.11	0.79	2.39	0.16	1.98	-	2.75	3.33	3.32	3.68	2.08	0.41	1.97	0.44
Private equity elasticity of issue	0.34	0.13	0.45	0.21	0.48	0.03	0.35	-	0.46	0.67	0.56	0.74	2.08	0.1	0.49	0.09
Private equity elasticity of issue	-1.42	2.83	-0.58	0.69	0.3	1.04	0.7	-	-0.88	-1.33	-1.97	-0.13	-3.53	3.37	0.12	0.35

It should be noted that the dynamics of productivity in recent years show that entrepreneurs risk losing competitiveness in the EU market. That's why the performance issues are more relevant than ever. Low productivity is a sign that the economic system is unable to allocate resources to produce high-value-added goods.

The analysis of shifts in the share of productivity growth shows that the productivity increase in the sector largely explains the overall development of labour productivity. However, the productivity gains due to the movement of labour from less productive to more productive sectors (the so-called "change effect"). The process of the efficient allocation of resources is a sign of a weak institutional environment. Therefore, it is important not only to promote innovation (in particular, FinTech development) but also to improve the efficiency of market resource mechanisms, minimizing costs and risks. This will increase the competitiveness of production and competitive advantage to attract more investment, especially in the context of the green economy development, one of the major axioms of which is the inability to infinitely expand the sphere of influence in a confined space, and the inability to demand endlessly growing needs in resource constraints.

As can be seen from table1 these indicators are multi-dimensional and multifaceted, characterized by a significant variation and do not provide an opportunity to fully generalize, evaluate and highlight the similarities of the countries that have become EU members since 2004 or highlight the peculiarity of their economic development and productivity.

This problem can be overcome by applying multidimensional economic and mathematical modelling, in particular, hierarchical cluster analysis. As a result, among the totality of indicators, a class of homogeneous units of the population was formed, a corresponding communication model was constructed and dendrograms were formed using hierarchical clustering procedures, which reflect the measure of similarity of countries in 1991-2003 (Fig. 2) and 2004-2017 (Fig. 3). As is seen in Fig. 2 the graph identifies three clusters that unite two countries. This means that each of these pairs of countries for the period 1991 – 2003 had similar values of economic growth. Thus, the Euclidean distance (*ED*) between Lithuania and Poland was only 1.12, between Hungary and Estonia-1.5, between Latvia and Slovakia – 4.78. The Czech Republic and Ukraine are apart from these countries. However, their Euclidean distances, which characterize deviations in economic development and productivity, are insignificant and practically do not differ from the existing clusters: from *ED*=2.49 (for the Czech Republic) to *ED*=4.19 (for Ukraine). The analysis of the dendrogram in Fig. 2 showed certain changes in the macroeconomic indicators of the studied countries in the multidimensional space for the period 2004-2017, that is, after the entrance of countries (except Ukraine) to the EU. Thus, the graph clearly shows two clusters: the first unites the Czech Republic, Estonia, Hungary, and Ukraine; second-Lithuania, Poland and Slovakia. However, even within a single cluster, the Euclidean distance between countries has a significant variation. Thus, for the first cluster, where the Czech Republic and Estonia were the most related to each other (*ED*=4.86), the distance to Hungary and Ukraine was as much as 16.14 and 20.51, respectively. According to the second cluster, the indicators of economic development and productivity are the most similar in Lithuania and Poland (*ED*=29.93). The analysis makes it possible to conclude the relative homogeneity of the indicators of the studied multidimensional space of the economic growth and

productivity of seven countries after their entrance to the European Union and a certain approximation of Ukraine to them. It should be noted that in Fig. 2. Latvia, for which the model of multiple regression of the labour and capital impact on GDP for the period 2004-2017 was built, appeared inadequate. Therefore, it is impossible to assess the changes in macroeconomic indicators of this country in the multidimensional space after joining the EU in comparison with other countries under the study.

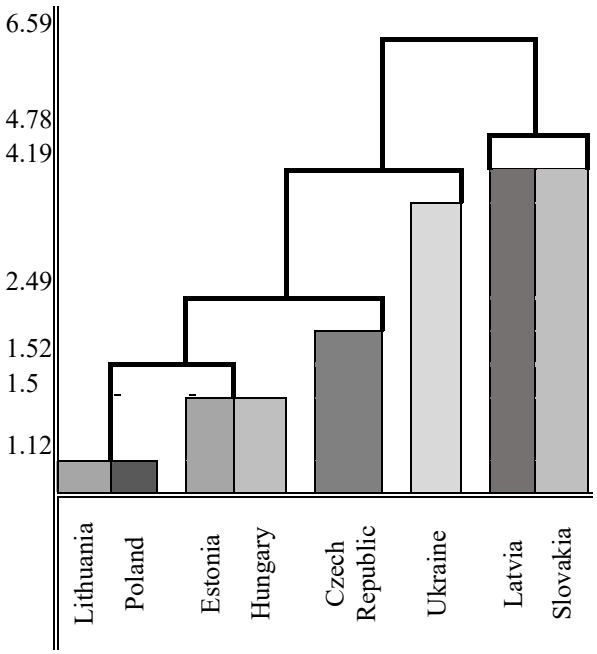

Fig. 2. Dendrogram of clusters (1991-2003).

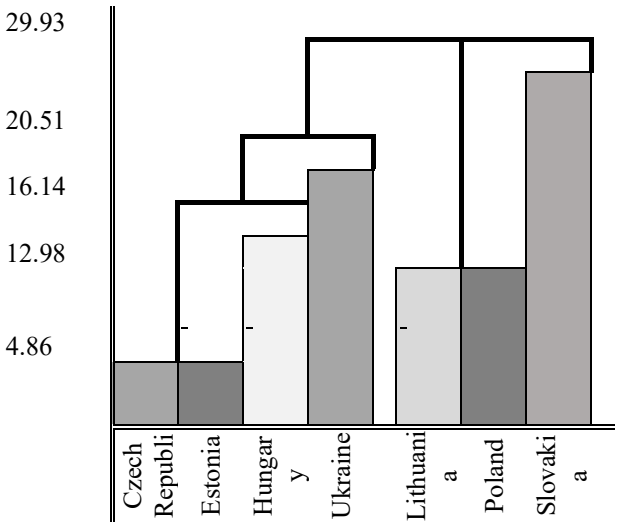

Fig. 3. Dendrogram of clusters (2004-2017).

Paying tribute to the two-factor multiplicative production function (Fig. 1), with the help of which a meaningful analysis of the economic development and productivity of countries was carried out, and despite the rather serious advantages of its application, namely non-linearity, dynamism, and simplicity, we should not forget about a number of its shortcomings. They include:
- the problem of the scale effect that cannot adequately represent the production process [16];
- the problem of establishing the parameters of the production function-indicators of elasticity of output by resources. Marginal prices of production factors are equal to average prices, which are calculated based on market prices, which is possible only in conditions of market equilibrium and perfect competition [16];
- ignoring the factor of complementarity – the neglect of capital structure in the production function [17].

After all, by [17] the decomposition of capital can be carried out behind such types of assets: the capital not related to the information technology (K_n), hardware (K_c), software (K_s), and telecommunications (K_t):

$$Y=AX\,(K_n, K_c, K_s, K_t, L) \quad (1)$$

Therefore, further studies must pay special attention and include the components of the capital of information and communication technologies in the set of factors of the model, especially considering the development of FinTech under the conditions of the digital economy.

It should be noted that changes in GDP are not always explained solely by changes in the volume of labour and capital, so it is necessary to carry out modelling of multifactor productivity (Total Factor Productivity (TFP)), which reflects the combined impact of many factors, such as changes in technology and, accordingly, in the professional skills of the workforce, changes in the use of resources, changes in energy prices, economy of the scale, research and development costs.

Another group of issues that need to be addressed in future research is:
1. The weakness of the information base. This reduces the reliability of conclusions and analysis in general. Short time series and poor quality of the initial data (and often their lack of representation in the time interval) make it difficult to obtain reliable econometric estimates;
2. The rapid changes and periods of acceleration and decline in Ukraine, in contrast to the steadily developing market economies where the pace of change is not high. That is, the market system in each subsequent period does not differ much from the previous moment, and the existing differences are considered by introducing minor amendments. Periods of intensification of processes in the crisis economy of Ukraine lead to a loss of comparability between neighbouring points of time series, which creates additional difficulties in the use of econometric methods.

All these problems lead to a focus on improving the quality of models through a thorough approach to the initial data, their preliminary analysis, harmonization, normalization, standardization, and forecasting.

5 Conclusions and suggestions

One of the main problems for Ukraine is the creation of new competitive advantages associated with investments in the latest technologies, innovations, research, human capital, efficient allocation of resources and redistribution, which is accompanied by changes in the behaviour of economic entities. Increasing the motivation of entrepreneurs is a major structural change in policy development. The process of structural economic transformation largely depends on the quality of the

institutional framework (legislation, state aid, and economic and political institutions), which ensures the efficiency of the market of goods and resources, minimizing the costs and risks of the redistribution process, thereby strengthening the competitive advantages of the country.

The research results of the Eastern European countries experience reflected the importance of the institutional environment for successful economic change. Accession to the European legal, economic, technological space contributes to the formation of the necessary quality of institutions in the new countries, which contributes to their productivity. Implementation of all terms set out in the EU-Ukraine Association Agreement has huge importance for Ukraine. The priority is to continue the policy of approximation of Ukrainian legislation system to the EU countries' system.

The main recommendation for government policy to increase the investment attractiveness of the Ukrainian economy are: to promote the diversification of human capital with the strengthening of its intellectual component; to support the conditions of innovative development of Ukrainian business to strengthen the technological level following global trends; to strengthen structural policies with a focus on the green economy by facilitating investments in environmental and environmental technologies, production of environmentally friendly products In order,;

The challenges of increasing national economic productivity are quite acute for Ukraine. Decades of transformational development have not formed a consistent trend of improving the quality of economic growth factors and long-term prerequisites for productivity gains. Therefore, improving the productivity of the national economy will be facilitated by improving the quality of traditional economic factors – labour and capital. Trends in the current development of transformational countries as well as countries with the emerging markets confirm the feasibility of intensifying non-economic factors. The most important of these factors are the characteristics of social capital, in particular, the institutional trust in society and civic engagement.

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Socio-political development of countries in information society. Countries of the EU

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Abstract. Many studies are devoted to the peculiarities of building the information society in the modern world and the problems of uneven development of information and communication technologies in developed and developing countries. This paper examines the influence of the information and communication technologies development on the social and political activities of modern society. The correlation and regression analysis has been used to identify the relationship between the Information and Communication Technology Development Index (ICT), the Human Development Index (HDI) and the Democracy Index (DI). The results demonstrate that there is a close link between the countries' socio-political attractiveness and the level of their information and communication development. However, it is not equal for different countries, which are grouped by the level of ICT, HDI and DI. Besides, the country's information and communication technologies level has a significant effect on the social and political development. The development of the information component immediately leads to improvement of the socio-political sphere in countries with high levels of HDI, DI and ICT. The EU countries belong to this cluster. Democracy development and ICT have the inverse relationship in the group of countries with average HDI, DI and ICT levels.

1 Introduction

The transition of the world society to the information society or knowledge society, the transformation of information technology into a generative force for the development of countries leads to the transformation of all spheres of human life. The ICT sector directly accounts for 5% of Europe's GDP, with a market value of € 660 billion. However, the level of influence of ICT on the overall growth of production is much higher (20% directly from the ICT sector and 30% from investments in this field) [14]. Despite substantial investments in ICT in the public sector over the past decades, it has been hard to achieve consistent benefits. One reason for the difficulties is the gap between the expectations of key stakeholders (such as governments, businesses and citizens) and project outcomes [16].

ICT contributes to economic, social and political changes in society. This can be done through formation of unified databases and global platforms for the exchange of knowledge and best practices in all areas of life. At the same time, new opportunities and threats confront modern society. On the one hand, global information provides equal opportunities for all countries to join the global information platform, and on the other, it contributes to the gap between countries based on using advanced technologies, reinforcing economic and social inequality. In spite of attempting to implement e-government innovations to enhance efficiency in public organizations for several decades, e-government innovation has often not met the expectations of citizens, legislatures, or the organizations [17].

In the 20th century the most developed countries gradually entered the state of information society and it is expected that within a matter of a few decades the majority of the world's population will be living and working in a global information society [1].

Based on the analysis of social reality in the second half of the 20th century, socio-historical reasons of "knowledge" and "information" concepts confusion have been defined. The relations between confusing these concepts and the formation of knowledge society concepts and information society ones are shown [2]. Across the European Union, indicators that measure information society emphasize many disparities and especially characteristics of this sector [3].

2 Theoretical development and hypotheses formulation

In recent years, progress in information and communication technology (ICT) has caused many structural changes such as reorganizing of economics, globalization, and trade extension, which leads to capital flows and enhancing information availability [21].

New character of cognitive processes is caused by the new informative means which have appeared together

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with the Internet, e-mail and system of mass communication. They connected the world in uniform space [4].

The Global Brain proposes a positive vision for a more sustainable society. The Global Brain can be defined as the distributed intelligence emerging from all human and technological agents as interacting via the Internet. It plays the role of a nervous system for the social superorganism [5].

The problems with current forms of electronic information systems (IS) implemented in human service organizations have been well documented and attention is now focused on how they might be redesigned for the future [18].

ICT carries the potential of opening economic opportunities, promoting social and political changes in society, providing access to knowledge, creating stimulus and a field for best practice sharing in all areas of life, the actual processes of informatization across the globe are quite asymmetrical [6]. Without internet access, which facilitates economic development and the enjoyment of a range of human rights, marginalized groups and developing States remain trapped in a disadvantaged situation, thereby perpetuating inequality both within and between States [7].

The statistical data points on the fact that it is necessary to increase the awareness of population regarding possibilities offered by using of ICT and e-Government in Latvia [8]. The development of the information society and the introduction of new ICT in all spheres of society is determined by a priority of national public policy [9].

The level of information today is decisive in the socio-economic development of the country [10].

There has been a proliferation of e-readiness assessment measures in recent years that each one has a certain objective. Based on definitions, objectives, dimensions, methods and approaches, in this paper, the measures are categorized and finally, a measure for e-readiness assessment is presented. The convergence measure for e-readiness assessment include some common indicators: infrastructure and access, access to and use of ICT by households and individuals, E-businesses, E-education, E-government, basic enabling indicators [9]. Contemporary enterprises can to improve the quality of information security solutions using structural analysis and design tools as CA All Fusion ERwin Data Modeler [10].

The impact of information society – as a factor of organizational change on performance of firms is increasingly approached and measured – by means of statistical indicators – in the specialty literature, developing in a fast pace. Across the European Union, indicators that measure information society emphasize many disparities and especially characteristics of this sector, aspects that will be detailed further, in this paper in order to justify the approach of this study [19].

The review of research induces us to formulate new hypotheses and enlarge the research sphere.

Hypothesis 1. There is a direct correlation between the information and communication level and the socio-political development of societies in the countries of the world.

Hypothesis 2. This impact may be different in countries with different levels of information and communication development.

3 Methods and data

The methods of multivariate statistical analysis, such as descriptive statistics, the multiple regression and the cluster analysis were used to study the influence of information and communication technologies on socio-political level of development. These statistical methods were implemented with the StatSoft software package Statistica. This package has a wide range of functional data analysis algorithms and has wide graphical capabilities for data visualization.

To carry out the research, the global indices and variables of socio- political development were selected:

The Information and Communication Technologies Development Index (ICT) reflects the level of networked infrastructure and access to ICTs, the level of using of ICTs in the society and more efficient and effective ICT use [15]. This database was created by ICT Data and Statistics Division Telecommunication Development Bureau International Telecommunication Union.

The Human Development Index (HDI) is chosen to reflect the level of social development. The HDI is the geometric mean of normalized indices for each of the three dimensions: a long and healthy life, being knowledgeable and have a decent standard of living. The Human Development Ranking use to measure a country's development by the United Nations Development Programme [13].

The Democracy Index provides a snapshot of the state of democracy worldwide. The Democracy Index is based on five categories: electoral process and pluralism, civil liberties, the functioning of government, political participation and political culture [14]. Such data is collected by the Economist Intelligence Unit (EIU), the world leader in global business analysis.

107 countries of the world are the objects of research. The variables are the data for 2017. The countries without sufficient data were excluded from the database.

4 Results

In order to study the influence of the country's information and communication development on the human development and level of democracy the following algorithm of the research is proposed:

Stage 1. Selection of the initial variables.

Stage 2. Research of the basic statistical characteristics of the selected variables (ICT, HDI, DI).

Stage 3. Verification of the first hypothesis on the basis of the correlation-regression analysis methods.

Stage 4. Verification of the second hypothesis on the basis of the correlation-regression and cluster analysis methods for the whole array of initial data and within the scope of separate groups of countries, which are similar a

according to the level of country's information and communication development.

The inferential statistics reveal that relative advantage, compatibility, complexity, observability, and security are significant factors influencing internet-based ICT adoption [20].

For implementation of the first stage of the algorithm, the following variables were selected: The Information and Communication Technologies Development Index (ICT), The Human Development Index (HDI) and The Democracy Index (DI).

Descriptive statistics were used to process, systematize and provide a quantitative description of the empirical data by means of the main statistical indicators. The implementation of the second stage of the study presupposed the calculation of the following characteristics: Mean, Median, Mode, Frequency of Mode, Minimum, Maximum, Variance, Standard Deviation, Coefficient of Variation, Skewness, Kurtosis, as well as histogramming. The results of calculation are presented in Table 1.

Table 1. Descriptive statistics.

Characteristics	Variable		
	ICT	HDI	DI
Valid N	107	107	107
Mean	5.292	0.733	6.069
Median	5.580	0.755	6.410
Mode	Multiple	Multiple	5.11
Frequency	2	2	3
Minimum	1.270	0.404	1.500
Maximum	8.980	0.953	9.870
Variance	4.967	0.023	3.815
Std. Dev.	2.229	0.150	1.953
Coef. Var.	42.12	20.47	32.18
Skewness	- 0.139	- 0.438	- 0.249
Kurtosis	- 1.252	- 1.252	- 0.638

The results of the histogramming of distribution for each of the studied variables are presented in Fig. 1 – 3.

According to the results of the analysis of the obtained statistical characteristics (see Table 1) and distribution histograms (Fig. 1 – 3), the following conclusions can be made:

- the ICT variable has a distribution rather close to normal. Its average value is close to the median. In 2017 this index had a significant spread (from 1,27 to 8,98), the value of this index in more than 45 countries differ from 6 to 9. This means that a significant part of the countries in the considered group has a high level of development of information and communication technologies (ICT);
- the HDI variable also has a distribution close to normal. This variable has the least value of the coefficient of variation (20,47 %).The value of this index in a little more than 50 % countries differ from 0,7 to 1, that is nearly half of the researched countries of the world gets into the last three intervals. It has an insignificant left-side displacement (the skewness is equal to -0,438);
- the DI variable has a distribution close to normal. This is evidenced by the proximity of the mean, mode and median, as well as small values of the skewness and kurtosis.

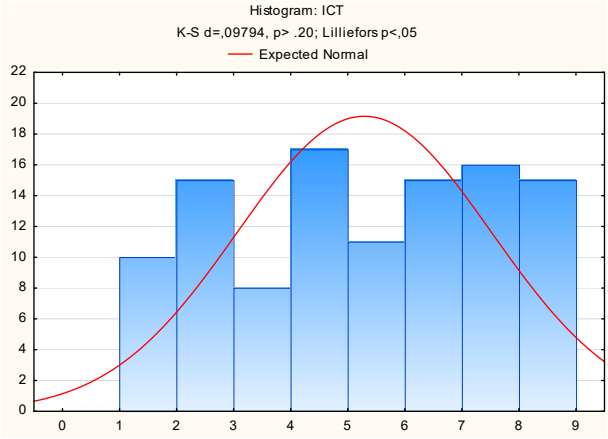

Fig. 1. ICT variable distribution histogram.

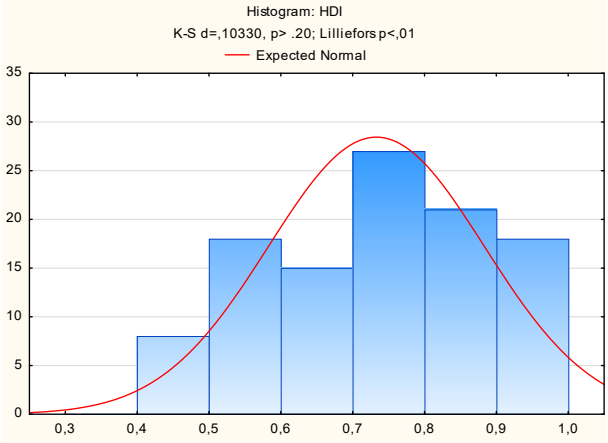

Fig. 2. HDI variable distribution histogram.

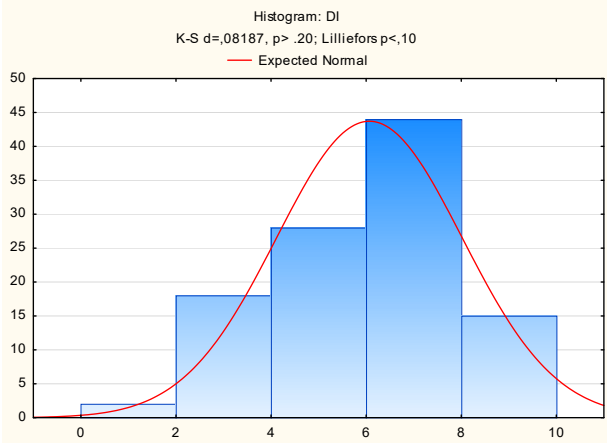

Fig. 3. DI variable distribution histogram.

Information and communication technologies (ICTs) are seen by many as a cost-effective and convenient means to promote openness and transparency and to reduce corruption [22].

ICT offer countries a new approach to creating transparency and promoting anti-corruption. Many nations with transparency laws have directly tied the implementation of these laws to the implementation of ICT-based initiatives, often through e-government.

Case studies and statistical analyses indicate that ICTs hold a great deal of potential for – and are already

demonstrating benefits in – anti-corruption, particularly by enhancing the effectiveness of internal and managerial control over corrupt behaviors and by promoting government accountability and transparency.

The verification of the first hypothesis that the information development of the society contributes to the improvement of the country's social progress was carried out during the implementation of the third stage of the study. A pair correlation coefficient between the HDI, DI and ICT variables was calculated according to the data from all 107 countries. In 2017 it was equal to 0.9665 and 0.6887, which demonstrates the link between DI and ICT and, conversely, HDI and ICT.

The graphic representation of this connection is given in Fig. 4.

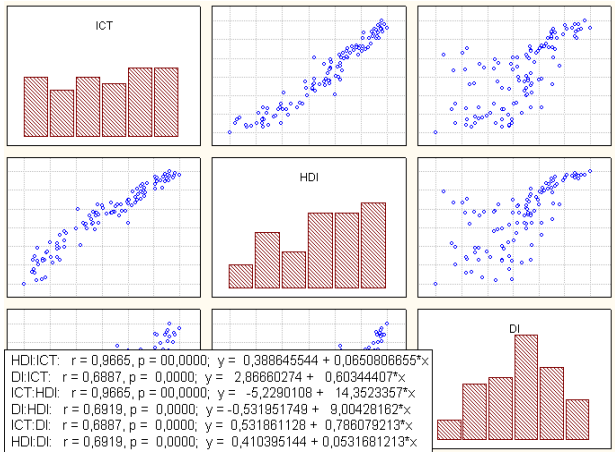

Fig. 4. Dispersion field (correlation field) between factors.

The dispersion field proves a linear relationship between DI, HDI and ICT. The closest connection is observed between ICT and the Index of Human Development (r=0,9665). There is also a correlation between ICT and DI, but it is less close (r=0,6887). Therefore, we can accept the hypothesis 1 that the greater the information development of the country is, the better socio-political sector is developed in this country. This enables putting forward the second hypothesis that this impact may be different in groups of countries identified in terms of their ICT levels.

To study the effect of ICT on HDI and DI, we construct a complex regression:

$$\begin{cases} \widehat{HDI} = a_{10} + a_{11} \cdot ICT, \\ \widehat{DI} = a_{20} + a_{21} \cdot ICT, \end{cases} \quad (1)$$

where a_{ij} – unknown parameters that are estimated with the help of ordinary least squares method (OLS).

Realisation of this model has been held with the help of STATISTICA package by gradual usage of OLS to each equation. The following results have been obtained:

$$\begin{cases} \widehat{HDI} = 0.3886 + 0.065 \cdot ICT, \\ \widehat{DI} = 2.8686 + 0.6047 \cdot ICT, \end{cases} \quad (2)$$

The data of regression equations are statistically significant on the whole by Fisher criterion ($F_{HDI}(1;105) = 1487.3$, $F_{DI}(1;105) = 95.45$), and by certain parametres by Student's criterion ($t_{a_{10}} = 40.14$, $t_{a_{11}} = 38.57$, $t_{a_{20}} = 8.08$, $t_{a_{21}} = 9.77$,). The coefficients of multiple correlation ($R_{HDI} = 0.966$, $R_{DI} = 0.69$), determination coefficients ($R^2{}_{HDI} = 0.934$, $R^2{}_{DI} = 0.476$) and adjusted determination coefficients ($R^2_{adj_{HDI}} = 0.933$, $R^2_{adj_{DB}} = 0.471$) prove high quality of the model for HDI and medium quality for DI. There is no autocorrelation of errors (statistics of Durbin – Watson approximately equals to 1.9, and cyclic coefficient of autocorrelation is rough 0) in the both models. So, we draw a conclusion that the given model can be used for analysis.

It can be noted that increase in ICT by one, will provoke increase in the HDI index approximately by 0.065, and index DI – by 0.605 unities. This influence is direct and statistically significant.

Thus hypothesis 1 is proved.

Realization of the fourth stage presupposes verification of the second hypothesis that states: intensity of information development effect on economic development of countries is heterogeneous and can increase or decrease in various countries groups.

The following steps are proposed to verify this hypothesis:

Step 1. Countries disposal into homogeneous groups by values of indices HDI, DI and ICT based on cluster analysis methods.

Step 2. Construction of complex regression of the kind (1) for each of the clusters.

Step 3. Making conclusions.

At the first step with the help of cluster analysis methods we obtain homogeneous countries groups. The countries can be quite clearly allocated into two, three or five clusters (Fig. 5) on the basis of Ward's hierarchical method.

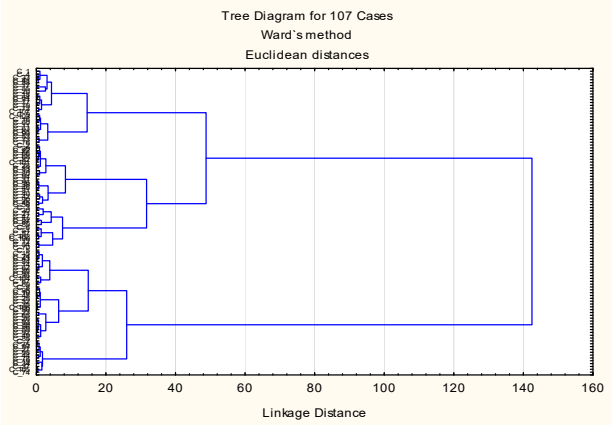

Fig. 5. Tree Diagram.

The division into two clusters is not informative. If we divide countries into five clusters, then the clusters with close average factor values will emerge. Therefore, it is rational to divide countries into three clusters, which corresponds to the logical distribution of countries with high, medium and low intensity of ICT development.

Based on the iterative method of clustering k-means, the following cluster results have been obtained. The first cluster includes 36 countries with the highest level of ICT

(cluster contains 36 cases). These countries are listed in Table 2.

Table 2. Members of Cluster Number 1 and Distances from Respective Cluster Center

Country	Distance	Country	Distance
Argentina	0.840	Finland	0.557
Australia	0.658	France	0.342
Austria	0.264	Germany	0.496
Belgium	0.181	Greece	0.535
Bulgaria	0.783	Hungary	0.947
Canada	0.620	Iceland	1.133
Costa Rica	0.748	Israel	0.192
Croatia	0.881	Italy	0.395
Cyprus	0.284	Japan	0.428
Czech Republic	0.417	Latvia	0.547
Denmark	0.874	Lithuania	0.492
Estonia	0.296	Mauritius	1.065
Netherlands	0.648	Slovenia	0.387
New Zealand	0.769	Spain	0.042
Norway	1.122	Sweden	0.857
Poland	0.943	Switzerland	0.807
Portugal	0.366	United Kingdom	0.599

Almost all EU countries (except Romania) are in this cluster. These countries have a high level of the Democracy Index (DI), information and communication technologies development (ICTs) and the Human Development Index.

The second cluster includes 41 countries with an average level of ICT (cluster contains 41 cases) and is presented in Table 3.

Table 3. Members of Cluster Number 2 and Distances from Respective Cluster Center.

Country	Distance	Country	Distance
Albania	0.27	El Salvador	0.99
Algeria	1.19	Georgia	0.37
Armenia	0.87	Ghana	0.97
Bolivia	0.56	India	1.62
Botswana	1.37	Indonesia	0.73
Brazil	0.91	Iran	1.79
China	1.42	Jordan	1.05
Colombia	0.65	Kazakhstan	1.74
Dominican Rep.	0.78	Kyrgyzstan	0.58
Ecuador	0.37	Lebanon	0.76
Egypt	1.31	Malaysia	0.86
Mexico	0.51	Saudi Arabia	2.24
Moldova	0.72	Serbia	0.92
Mongolia	0.58	South Africa	1.00
Montenegro	0.68	Sri Lanka	0.96
Morocco	0.49	Thailand	0.57
Panama	0.91	Tunisia	0.52
Paraguay	0.77	Turkey	0.60
Peru	0.60	Ukraine	0.22
Philippines	0.76	Russian Federation	1.72
Romania	0.87		

Countries in the cluster 2 are characterized by the average level of ICT and socio-political development. Ukraine is referred to this group.

To further develop the understanding of the conditions of unrealized benefits of e-government innovation, we propose a conceptual framework of a knowledge vacuum, which is an organizational condition in which excessive exploration and organizational inertia interact to create a vicious cycle of low performance. We first review the history of e-government and factors that affect the success and failure of e-government innovation.

The third cluster includes 30 countries with the low level of ICT (cluster contains 30 cases). This cluster is presented in Table 4.

Table 4. Members of Cluster Number 3 and Distances from Respective Cluster Center.

Country	Distance	Country	Distance
Afghanistan	1.089	Ethiopia	0.707
Angola	0.516	Guatemala	1.016
Bangladesh	0.612	Guinea	0.803
Benin	0.760	Honduras	0.925
Burkina Faso	0.368	Kenya	0.513
Cambodia	1.166	Lao PDR	1.197
Cameroon	0.445	Lesotho	1.355
Chad	1.789	Madagascar	0.595
Malawi	0.748	Pakistan	0.072
Mali	0.744	Rwanda	0.699
Mauritania	0.334	Senegal	1.032
Mozambique	0.221	Tanzania	0.717
Myanmar	0.468	Uganda	0.429
Nepal	0.537	Zimbabwe	0.764

Countries of the latter cluster are characterized by the lowest level of ICT, HDI and DI.

This is also confirmed by the calculation of the pair correlation coefficients between the variables for each cluster separately. The results of calculations are presented in the Table 5.

Table 5. Matrices of the pair correlation coefficients for each cluster.

Cluster 1			
Variable	ICT	HDI	DI
ICT	1	0.898	0.697
HDI	0.898	1	0.743
DI	0.697	0.743	1
Cluster 2			
Variable	ICT	HDI	DI
ICT	1	0.740	-0.442
HDI	0.740	1	-0.364
DI	-0.442	-0.364	1
Cluster 3			
Variable	ICT	HDI	DI
ICT	1	0.750	0.244
HDI	0.750	1	0.186
DI	0.244	0.186	1

We analyze the means of the obtained coefficients in more detail.

Firstly, cluster number 1 is formed from countries with the highest values of indices ICT, HDI and DI. The second cluster is constituted by countries with a middle level of ICT, GC and DI. The third cluster comprises countries with the lowest level of ICT, HDI and DI.

At the second step of the proposed algorithm we build complex regression of the kind (1) and get the following results.

For cluster 1 (with a high level of development):

$$\begin{cases} \widehat{HDI} = 0.473 + 0.054 \cdot ICT, \\ \widehat{DI} = 1.625 + 0.836 \cdot ICT, \end{cases} \quad (3)$$

The data of the regression equation are statistically significant on the whole by Fisher criterion ($F_{HDI}(1;34) = 142{,}18$, $F_{DI}(1;34) = 32{,}08$), and by certain parametres by Student criterion ($t_{a_{10}} = 13.51$, $t_{a_{11}} = 11.92$, $t_{a_{21}} = 5.66$,). But parameter a_{20} is statisticaly unsignificant ($t_{a_{20}} = 1.42$; *P–value* = 0.16). Coefficients of multiple correlation ($R_{HDI} = 0.898$, $R_{DI} = 0.697$), determination coefficients ($R^2{}_{HDI} = 0.807$, $R^2{}_{DI} = 0.485$) and adjusted determination coefficients ($R^2_{adj_{HDI}} = 0.801$, $R^2_{adj_{DI}} = 0.47$) indicate not quite high quality of the model.

For cluster 2 (with a middle level of development):

$$\begin{cases} \widehat{HDI} = 0.526 + 0.041 \cdot ICT, \\ \widehat{DI} = 9.144 - 0.683 \cdot ICT, \end{cases} \quad (4)$$

The data of regression equation are statistically significant on the whole by Fisher criterion ($F_{HDI}(1;39) = 47.158$, $F_{DI}(1;39) = 9.49$), and by certain parameters by Student criterion ($t_{a_{10}} = 16.29$, $t_{a_{11}} = 6.87$, $t_{a_{20}} = 7.69$, $|t_{a_{21}}| = 3.08$). Coefficients of multiple correlation ($R_{HDI} = 0.74$, $R_{DI} = 0.442$), determination coefficients ($R^2{}_{HDI} = 0.547$, $R^2{}_{DI} = 0.196$) and adjusted determination coefficients ($R^2_{adj_{HDI}} = 0.536$, $R^2_{adj_{DI}} = 0.175$) indicate the model quality which is a little lower than for the model (3).

It should be noted that this cluster is also characterized by inverse relationship between HDI and DI. The even correlation coefficient between these indicators is equal to -0.364 (see Table 5).

For cluster 3 (with a low level of development):

$$\begin{cases} \widehat{HDI} = 0.327 + 0.085 \cdot ICT, \\ \widehat{DI} = 3.079 + 0.541 \cdot ICT, \end{cases} \quad (5)$$

By Fisher criterion only the equation for HDI ($F_{HDI}(1;28) = 36.09$) is statistically significant on the whole, while for DI $F_{DI}(1;28) = 2.95$, and significance $F = 0.0955$. By Student criterion the significant parametres are a_{10}, a_{11} and a_{20} ($t_{a_{10}} = 9.3$, $t_{a_{11}} = 6.0$, $t_{a_{20}} = 3.07$), while the parametre a_{21} is statistically insignificant ($t_{a_{21}} = 1.33, P - value = 0.19$). Coefficients of multiple correlation ($R_{HDI} = 0.75$, $R_{DI} = 0.244$), determination coefficients ($R^2{}_{HDI} = 0.563$, $R^2{}_{DI} = 0.06$) and adjusted determination coefficients ($R^2_{adj_{HDI}} = 0.547$, $R^2_{adj_{DI}} = 0.026$) differ significantly for these two equations that indicates quite high quality of HDI model and low model quality for DI.

Analyses values of regression coefficients in models (2) – (5) that are given in Table 6 to research the changes in the influence of ICT on HDI and DI in each cluster.

Table 6. Regression coefficients.

Model	Coefficients	Total	Cluster 1	Cluster 2	Cluster 3
HDI	a_{10}	0.3886	0.473	0.526	0.327
	a_{11}	0.065	0.054	0.041	0.085
DI	a_{20}	2.8686	1.625	9.144	3.079
	a_{21}	0.6047	0.836	-0.683	0.541

As we can see from Table 6 a higher value of Intercept (a_{10}) is characteristic for cluster 1 by the HDI index in comparison with the whole set of data, but the lowest value of the slope angle (a_{11}) of the regression line. Cluster 2 is characterized by the highest value of Intercept (a_{10}), and a little lower of the value of a_{11} in comparison with other clusters and the whole option. Cluster 3 is characterized by the lowest value of Intercept (a_{10}), but the highest value of the slope angle (a_{11}) of the regression line. It means that the speed of HDI reaction to ICT increase will be the lowest for cluster 2, and the highest for cluster 3.

The situation is similar to DI index. The change speed of DI index under the influence of ICT is the lowest for countries with a low level of economic development and the highest for countries from cluster 1. But «the starting conditions», that is the coefficient value a_{20}, are much higher for cluster 2.

Thus, based on the aforementioned, hypothesis 2 for all groups of the countries is rejected.

Further researches are aimed at studying the stability of the identified dependencies over time.

5 Conclusion

The study allows us to draw such conclusions:

1) the result of the correlation-regression analysis indicates that there is a strong correlation between ICT and HDI levels, and a moderate correlation between ICT and human development. Therefore, the first hypothesis was confirmed;

2) in countries with high levels of HDI, DI, and ICT, the link between these indicators of societal development is higher than average. Accordingly, the development of the information component immediately leads to the improvement of the socio-political sphere. The EU countries belong to this cluster. At the same time, EU candidate countries (Albania, Northern Macedonia, Serbia, Turkey, Montenegro) belong to the second cluster, in which the impact of ICT on other spheres of life is different, which creates additional difficulties for the formation of united informational, social, economic and political space;

3) an unexpected result was obtained during the study of the group of countries with average HDI, DI and ICT levels. The distribution field and correlation-regression analysis indicate the inverse relationship between DI and ICT. This is because the spread of Internet technologies and social networks provides a powerful tool for manipulation of public opinion, which is especially relevant when applying political technologies. Studies have shown that this does not always lead to improvements in electoral process, civil liberties, government functioning, political participation, and

political culture. These contrasts can stimulate debate about government policy priorities.

The suggested model can be also detailed and extended according to the dynamic of Information and Communication Development Index, Human Development Index and Democracy Index over time. Moreover, considerable disparities are also related to the different economic past of the countries (developed countries, developing countries, politically unstable countries) and thus the model suggested for this paper can be completed with qualitative variables.

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Regionalization of the world as the key to sustainable future

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Abstract. Globalization is viewed not only as the objective, but also as the subjective process, the current version of which requires adjustments since it is characterized by the increasing inequalities and instability, causing conflicts worldwide, pushing regional groups towards confrontations. Globalization is to be directed for achieving the equitable levels of development across the globe for which it is suggested to establish the situational governing board as the common platform for collaboration between the regional blocs for global economy regulation. The notions of the regional state and the global/planetary state are introduced. The interdependence between regionalization and globalization is thoroughly analysed, which results is the explanation of the logic behind the process of the multipolar world formation as opposed to the unipolar one. The main points are illustrated by the facts from the EU integration history, WTO practice, the calculated indicators of the major thirteen regional integration groupings covering Europe, Asia, North, South America, Africa, two transregional organizations - Regional Comprehensive Economic Partnership, Transatlantic Trade and Investment Partnership, as well as the USA, Developed economies of Europe, China. The contribution to the study of regionalism as the boosting phenomenon shaping the development of the world allowed to conclude that regionalization is critical for the sustainable future of the world.

Introduction

Regionalization as the formation of blocs of states in one form or another has always been inherent to the development of the world. From the historical perspective the initiation of the regionalization process played its brilliant role in uniting and strengthening Europe in the 50s of the 20th century where for ages attempts had been made to create regions of peace, prosperity, and cooperation, thereby eliminating the causes of tensions and conflicts between some states [1].

After the end of the Cold War, the world became more ideologically homogeneous. There were subsequent attempts to build systems of collective security, and even elements of world statehood – through human rights or economic treaties and in the functionally differentiated sphere of security [2, p. 3]. Despite those attempts, notwithstanding globalizing forces and the emergence of elements of global constitutionalism and security, the world has been reverting to nationalist statism, militarized conflicts and arms races. Lately, the shift in the global power balance has accelerated, the international system has come under strain, and the competition between major countries has intensified.

In the mentioned above context the general number of regional agreements had increased quite significantly, from 445 in 2011 to 669 in 2018. An evolution of the depth of regional integration is noticeable as well, as listed in 2018 by the World Trade Organization (WTO). In fact, 29 customs unions (only 9 in 2011) and 150 Economic Integration Agreements have entered into force. About 60% are still composed of Free Trade Agreements (FTA; 250) and Preferential Trade Agreements (23). Moreover, if 50% of those regional agreements were bilateral in 2011, 66% are plurilateral and only 33% bilateral in 2018. In the end, 175 of those agreements are cross-regional [3].

Notable increase in the number of integration projects in different regions of the world from the mid-1980s transformed regionalism into global phenomenon full of substantial and organizational variations and an important element of the overall architecture of world economy and safety [4].

Thus, it is important to ensure that the regionalization processes are directed to contribute to the sustainable development which is to remain the prevailing trend for the future of the world.

The objective of the paper is twofold:

first, to reveal the interdependence between the regionalization and the globalization processes, to explain the logic behind the process of the multipolar world formation;

second, to demonstrate that the sustainable development on the global level requires attaining the state of unity in the diversity, the peaceful co-existence of the major states and regional blocs, and to show that the sustainable development of the regional groups ensures the sustainable future of the world.

The scientific novelty of the research:

1) the notions of the regional state and the global/planetary state are introduced;

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2) the dialectical relationship between regionalization and globalization is revealed;

3) the theoretical results are confirmed by the calculations of indicators taken from UNCTAD handbooks of statistics, and it is proved that the further integration of the leading regional blocs and/or major states of the world economy is highly unlikely.

1 Globalization and global economy

1.1 Globalization as the objective and subjective process contributing to sustainable development of the world economy

The analysis of many definitions of the term "globalization" allows us to conclude that although the globalization is the objective process, most of the scientists believe that the current version of globalization requires adjustments and thereby recognize the existence of the alternative ways of its further evolving.

For the illustration of the above-mentioned point the brief information on some approaches to the notion is given in table 1.

Table 1. Some approaches to the concept of globalization in scientific literature.

Description	Scholars
Globalization – in the simplest sense – an umbrella concept that seeks to capture the growing interconnectedness and integration of human society at the planetary scale.	A. Jones [5]
Globalization is variously understood to mean internationalization, liberalization, universalization, and planetarization. "Globalization" – with its connotations of *a development, a process, a trend, and a change* – is a relatively new word, coming into use during the latter part of the 20th century.	R. Robertson, J. Scholte [6]
The term 'globalization' often refers to changes in technologies of communication and transportation, increasingly internationalized financial flows and commodity trade, and the transition from national to world markets as the main arena for economic competition. The information age and the stage of global capitalism are asserted to constitute a new and qualitatively different historical epoch.	M. Castells, L. Sklair [7]
Globalization is largely a coincidental by-product of the welfare-democratic revolution in the institutional order in the most advanced post-war societies.	E. Rieger, S. Leibfried [8]
The term is used to refer to what has been called the 'Washington Consensus', or the 'globalization project'.	McMichael [7]
A new-hegemonic neoliberal political ideology that celebrates the victory of capitalism over socialism and proclaims marketization and privatization as solutions to the world's problems.	Ch. Chase-Dunn, Yu. Kawano, B. D. Brewer [7]

As has been described in table 1, globalization is not only the objective, but also the subjective process. Since globalization is the result of the synergistic effect of the many manageable processes (e.g. the peculiarities of the international division of labor, internationalization, regional integration of the world economy, etc.), its directions and intensity can be changed, corrected, managed, completely reformed, and thus it is possible to state that globalization can be governed as well.

1.2 Global economy formation: pros and cons

In our opinion, since the globalization is viewed as the objective and subjective process the issue of the formation of global governance and the development of regulatory mechanisms of the global economy becomes relevant, complex, and of vital importance for sustainable development of the world.

Theoretically, if we pursue an objective of establishing the global regulation institution, the formation of the supranational authorities of the regional organizations may be taken as an example, but it is important to keep in mind that the world is much more complex as the object of research in comparison with the region, a part of the world.

The controversial issue of the global economy creation brings up the problem of its polarity.

First of all, if we view *globalization as the process of the single holistic planetary state formation*, then, secondly, we can state that *the final stage of the globalization process is the unipolar world establishment*. And then, thirdly, it looks logical to assume that *this single world pole is to take up, incorporate, 'inherit' the sovereignty and power of all the nation-states* currently existing in the world, which originally formed the Westphalia system and were more or less independent players in terms of building their relations on the international arena. It's important to keep those points in mind.

It should also be mentioned that only in the 20th century the countires began 'to blur' by transferring their sovereignty up and down, and presumably to the global level itself, i.e. to that single pole, contributing to the global economy creation and global government formation.

After the US victory in the Cold War, the post-bipolar world became unipolar, formed by the United States and its allies. However, the modern global system is still sometimes called post-bipolar since the world had two poles for more than forty years: the capitalist pole formed by the US and its allies, and the socialist pole formed by the USSR and its allies. To sum up, *if the future global economy is to be unipolar, than at this stage of the world development it would highly likely mean approving US as the single pole and retaining their true status as the world leader, or hegemon.*

The U.S. are reviewing their role and underline that "in recent years, there has been a shift from the post-Cold War era to a new international security situation characterized by renewed great power competition between the United States, China, and Russia" and mention that the leading observers refer to the new situation as tripolar or multipolar world [9].

As mentioned in the summary of the document, the U.S. role in the world can be described in general terms as consisting of four key elements: global leadership; defense and promotion of the liberal international order; defense and promotion of freedom, democracy, and human rights; and prevention of the emergence of regional hegemons in Eurasia [9].

China, in its turn, emphasizes the need to improve global governance. China believes that guided by a strong commitment to multilateralism, countries should make active efforts to advance the rule of law and democratization of global governance. "Given the governance deficit, peace deficit and development deficit in our world, there is a pressing need to strengthen and improve global governance" [10].

According to B.Hettne and F.Soderbaum, the current global situation needs to be related to the structural transformation of the world, including (a) the move from bipolarity towards a multipolar or perhaps tripolar structure, with a new division of power and new division of labour; (b) the relative decline of American hegemony in combination with a more permissive attitude on the part of the USA towards regionalism; (c) the erosion of the Westphalian nation-state system and the growth of interdependence and 'globalisation'; and the changed attitudes towards neoliberal economic development and associated political system in the developing countries, as well as in the post-communist countries [11].

Under the conditions of a unipolar or bipolar world order it is logical to speak not of the globalization of the world, but of maintaining or opposing the hegemony of one state and its allies or increasing conflict between the two. There is no need to prove that the ties between the West and the East, the US and China, the Western civilization and the other civilizations might become even more tense and could result in confrontations.

It is necessary, before proceeding, to underline that at the end of the second decade of the twenty-first century, the dominant position in the world space is occupied by the Western civilization, the rise of which is largely due to the effects of various factors, e.g. – religious – the spread of Protestantism; political – the democratization of society, the formation of "melting pot" model and the active stage of the regional integration processes; economic – the spread of liberalism. Nevertheless, the logic of the deployment of the historical dynamics of human development indicates the inevitability of changing the current situation through prolonged civilizational conflicts [12, p.75].

In our opinion, *to make the universe a safer place for all, to ensure the conflict-free environment in the diversed world, it is of vital importance to establish a multipolar world in which the poles reflect the civilizations and/or economic and political centers, representing the regions, for the sustainable world development*. Thus, within the modern scientific debate on the burning issue we would like to agree with the researchers who support the idea that the unipolar world formation, as well as the global government should be rejected, and replaced with *the situational governing board for global economy regulation with strong and equal representation of all the existing and soon-to-be-formed poles with equal political rights to make global decisions by consensus*.

2 Interdependence between regionalization and globalization

2.1 Fundamental difference between regionalization and globalization

The analysis of publications shows that there are different views on the interdependence between regionalization and globalization. Some scholars consider regionalization an integral part of globalization, while others - as an alternative to it.

However, according to the definitions, the regionalization process results in the unification, consolidation or integration of some countries, national economies, while the globalization process aims at strengthening interconnectedness and greater unity of all the states of the world. So, it is easy to imagine regionalization as an interaction of two or more countries (or groups of countries), but it is nearly impossible to envisage globalization in the same way, since the concept of globalization extends to all the existing countries and covers all the groups of states. Therefore, the two concepts can be compared and contrasted: but their targets are different in scope – regionalization focuses on some countries, globalization – on all the countries of the world; both globalization and regionalization are the objective and subjective processes, and the former presupposes enhancing the unity of the whole world, the regionalization – the unity of a certain region, just some part of that world.

At the same time the law of the international division of labor forms the basis for both processes. The information and communication technologies shape both processes, but the degree of embrace of internationalization on the global level is higher in comparison with the regional level, and in the regional integration organization it varies within certain limits depending on the depth of coverage as mentioned in the agreement and the type of integration stage. Moreover, regional integration contradicts the main principle of multilateral cooperation, which is the basis of globalization, the principle of equal participation in it for all [13, p. 58].

The scholars suggest the New Regionalism Approach as a broad, open-ended framework for analysing regionalization from a multilevel and comparative perspective in order to understand the complexities of present-day regionalism, and to pay the required attention to the distinction between regional and world approaches [14]. The publications of the regional integration prove that there is an obvious tendency towards studying the feasibility of launching integration blocs, keeping and/or enhancing their sustainability and capacity building, as well as the prospects for their development in general [15, 16, 17].

Indeed, if we focus on the fact that regionalization segregates a group of countries from the rest of the world, their totality, then we can formally state that

regionalization weakens the unity of all the countries, leads to certain localization, even deglobalization. This way of thinking would be appropriate if the totality of countries had already been formed/united.

Grzegorz Kolodko, responding to a question about what the future holds for the world, noted that regional integration contributes to, rather than counteracts, the unification of the world and the globalization of the economy. In the future, instead of almost 200 countries and their national economies, we will increasingly be dealing with 10-20 groups that will be confronting political, cultural, social, economic, structural, and institutional issues of the world [18, p. 169–170]. In our view, regionalization leads to advantageous globalization for all if it is carried out in a more balanced and responsible manner, consistently in time and space.

2.2 Glocalization and the interrelation between regionalization and globalization

The following point deserves attention: the fragmentation of regional organizations leads to globalization through the process of glocalization, the formation of a single global space by disintegrating/ fragmenting the parts that form it. To make space homogeneous, it is advised to grind the elements that form the whole, so that they become homogeneous mass. The main point here is that the idea of regionalism as an ideology of globalism is justified. The purpose of regionalism is to replace the central role of the nation-state in international relations by a region, obtained either by the fragmentation of the space of the state or by the unification of the territories of several states [19, p. 175–179].

On the one hand, it is hard not to agree with the view on the interrelations between globalization and regionalization, expressed in many modern studies, where it has been argued that globalization is not the process of all-states-inclusive-dynamic-development in general, but that of degradation and further isolation, which increases inequality, poverty, instability, etc. On the other hand, it is certainly true that ideally globalization should aim at achieving equitable levels of development across the globe, i.e. at ensuring the sustainable economic development. According to the Polish sociologist and philosopher Zygmunt Bauman, globalization is not so much about forming a better world, but is about increasing inequalities, enhancing fragmentation, and ultimately is the product of "the individualized society".

Klaus Schwab puts it quite eloquently that "the critical danger is that a hyperconnected world of rising inequality may lead to increasing fragmentation, segregation and social unrest, which in turn creates the conditions for violent extremism. The fourth industrial revolution will change the character of security threats while also influencing shifts of power, which are occurring both geographically, and from state to non-state actors. Faced with the rise of armed non-state actors within what is already an increasing complex geo-political landscape, the prospect of establishing a common platform for collaboration around key international security challenges becomes a critical, if more demanding challenge" [20, p.77].

On the one hand, ***the integration progress on the regional level*** has been described with the help of the integration stages: free trade area, customs union, common market, economic union, etc. Those stages of integration processes are characterized by the transformation of the role of the nation state in the transition from free trade agreement to full integration, when the functions of nation states are given to the supranational authorities. The transformation of the nation-state in the regional integration grouping is described in detail, the stages of integration are determined, thoroughly reviewed and updated in the scientific literature.

Finally, it should also be noted that regional integration processes have their beginning and end while the globalization processes do not. It is also quite clear to most researchers what the "old" or "new" regionalism is, and what kind of logic stands behind it.

On the other hand, ***the integration progress on the global level*** has not been studied properly yet, especially in terms of the global planetary state formation and the changes of its functions in the globalization process. The concept of the global state has not been fully elaborated yet, there are only some approaches to the definition of the global economy, the development stages of which have not been identified yet.

We will add that regional integration processes take place through "top-down" integration and "bottom-up" integration, through state intervention and market forces. It is impossible to speak of globalization in the same sense, because at the global level there is no "top", there is only the interaction of states with formally equal rights, but different economic and military capacities.

However, abstractly it is possible to view the process of globalization as sequential increasing complexity and enlargement of regional organizations. But such a model of globalization has the contradiction that manifests itself in the fact that regional groupings obviously become economically more capable of self-preservation than the states that form them.

As mentioned earlier, the impression is created that the formation, enlargement and unification of regional integration organizations brings us closer to the final stage of the globalization, but at the same time in reality the establishment of regional integration blocs can segregate the countries inside this bloc to such an extend that their further integration with the other groupings or countries becomes more and more challenging, and it takes much more effort to carry forward that unification and to continue with integration even at the regional level, especially in comparison with the initial stage of the establishment of a regional integration organization.

Thus, *the result of the process of formation of regional integration organizations may appear to be not practically feasible at a certain stage, when these organizations consider further integration not useful for their future sustainable development.*

2.3 Disintegration in the processes of regionalization and globalization

It is certainly true that integrating countries should fulfil some economic and political pre-conditions before entering into any stage of integration. The major pre-conditions are related to the healthy 'economic fundamentals' of their economies, their competitiveness, and their ability to stand up to consequences of restructuring processes. If disparities in economic development among integrating countries exist when they commence the integration process, barriers to successful integration could appear [17].

It should also be borne in mind that *currently existing regional organizations may not only be integrated with the others, but also may fall apart or be divided into countries or some parts of those countries in order to further form other regional configurations.*

Integration and disintegration are objectively interrelated processes. Moreover, disintegration forms the preconditions for integration on a new quantitative and qualitative basis. In some cases, conditions for reintegration may be created. The reintegration can be described as full, partial, or extended. In the first case, we are focusing on the renewal of this or that integration grouping with the previous composition of member-states on the same political and economic grounds. Partial reintegration takes place when some members of integration groups are joined on the basis of previous principles or all participants, but on a qualitatively new basis. The extended integration is characterized by the inclusion of new members on a qualitatively new basis [21, p. 79].

Agreed disintegration means getting out of certain integration processes based on agreements between countries. This civilized, modern and legal mechanism provides an opportunity for all countries to prepare for changes in the rules and conditions of economic integration, minimizing objectively negative social, economic and political consequences (exit of the Baltic states from the free trade regime with Ukraine as a result of their accession to the EU, negotiations between the USA, Canada and Mexico on revision of the agreement on the formation of NAFTA/USMCA, etc.) [22, p. 8].

Brexit may serve as an example of the disintegration processes. Consequently, it proves the weakening of regional integration in the Western Europe, its fragmentation. At the same time, we cannot jump at the conclusion that it has led to the process of reverse globalization, to the fragmentation of the world economy; instead, there is all the evidence to state that there is more or less successful development of existing regional integration organizations in the modern world, as the indicators show in table 2.

For our purposes, it's important to draw the attention to the fact that the advancement of regional integration, its consistent transition from free trade agreement to full integration, results in the strengthening of the internal ties of the member states, and consequently – the weakening of their external ties, i.e. the economic relations with the third countries contributing to the segregation of the organization.

Table 2. GDP of the main regional integration blocs of the world (based on *UNCTAD Handbook of Statistics 2016*)*.

Regional blocs, stages of the integration process	GROSS DOMESTIC PRODUCT		
	Nominal gross domestic product of the regional integration bloc, 2015, millions of dollars	Regional integration bloc gross domestic product in total world domestic product 2015, %	Per capita nominal gross domestic product of the regional integration bloc, 2015, millions of dollars
1. The European Union (EU), economic and monetary union	16 067 827	21,49	31686,7
2. Eurasian Economic Union (EEU), economic union	1 550 510	2,07	8636,2
3. Association of Southeast Asian Nations (ASEAN), free trade area	2 453 031	3,28	3879,5
4. South Asian Association for Regional Cooperation (SAARC), free trade area	2 802 915	3,75	1607,3
5. The Cooperation Council for the Arab States of the Gulf, originally known as the Gulf Cooperation Council (GCC), customs union	1 725 744	2,31	32751,5
6. North American Free Trade Agreement (NAFTA, now USMCA), free trade area	20 648 136	27,62	42266,7
7. Southern common market (El Mercado Comun del Sur, MERCOSUR), customs union	3 504 079	4,69	11982,1
8. Andean Community of Nations (CAN), customs union	632 204	0,85	5937,6
9. The Pacific Alliance (Alianza del Pacifico, AP), free trade area	1 874 041	2,51	8344,9
10. East African Community (EAC), customs union	154 208	0,21	887,9
11. Common Market for Eastern and Southern Africa (COMESA), customs union	613 884	0,82	1418,6
12. Southern African Development Community (SADC), free trade area	608 983	0,81	2444,3
13. Economic Community of West African States (ECOWAS), customs union	663 670	0,09	1900,8

*World GDP 2015 – 74753058 mln US dollars.

Since the enhancing of the internal ties in the balance of all the ties automatically weakens external ties, it leads to the weakening of the integrity, cohesion of the global economy, its deglobalization, and fragmentation.

And since globalization is to end up with the single planetary state creation, then during the globalization process the number of countries is to be reduced till the only one is left which is to be called a global state. However, we cannot state that the number of countries in the world is decreasing.

Theoretically, *the regionalization process leads to the establishment of the regional state which substitutes the nation states.* In this case, the regional state, replacing the nation states, reduces the number of countries in the world, thus contributing to the global economy formation. And if the process continues and the newly-formed complex regional states are united into bigger integration blocs, then the whole process leads to the creation of the single planetary state/global state.

Thus, we have defined the newly introduced and grounded notions of the regional state and the global/planetary state.

2.4 Dialectical relationship between regionalization and globalization processes

With the above-mentioned points in mind, we can conclude that, on the one hand, regionalization leads to deglobalization, since integration at the regional level improves the strengthening of unity at the local level, and the weakening of unity at the global level. However, on the other hand, the formation of a regional state dismantles the group of nation-states and strengthens the global unity.

The key point is that regionalization leads to globalization, to the reduction of the number of nation-states in the world, but under certain condition, namely - when the formed regional grouping reaches the state of full integration and through a political treaty becomes a regional state instead of the totality of nation-states, on the basis of which it was created.

Finally, it can be argued that those processes of regionalization that are currently shaping the world economy, are actually limited by the concluded free trade agreements, established customs unions, common markets, etc., as it is shown in table 2. So, they, on the one hand, increase the overall efficiency of economic processes and enhance regional integration, but, on the other hand, do not substantially bring the world closer to political unity.

In summary, the strengthening of regionalization processes, that is, the increased segregation of the established and developed regional organizations, ***weakens the global cohesion of the world***. Moreover, if the above-mentioned processes result in the political union – a regional state, conditions are created to unite these new complex regional states and thus move us closer to the time of formation of a single planetary state. It is important to underline, that the processes of regionalization, on the one hand, by the time they are completed and the political union is formed – a new regional state – are contributing to a single planetary state formation, and, on the other hand, they are weakening the unity of the world. But at the same time the unification of new regional powers ***strengthens the global cohesion of the world***, given that such dynamics of regionalization development leads to a reduction of the number of states in the world through their unification.

Until the process of regionalization reaches the establishment of the new, more economically powerful regional state, it aims at reducing the unity of the world. But by completing this process, regionalization creates the conditions for a leapfrog to strengthen the unity of the world by uniting new powerful regional states. However, such powerful new regional states may not be interested in losing their independence and even decide to segregate or join some of the similar powerful new states to form separate unions. So, ***the above-mentioned detailed explanation helps to understand the logic behind the multipolar global world formation as opposed to the unipolar world maintaining.***

An example of dialectical relationship between regionalization and globalization processes is the fate of the WTO. Regional trade agreements have increased in number, as well as complexity since the early 1990s. One of the most frequently asked questions is whether these regional groups help or undermine the WTO's multilateral trading system. In spite of the WTO position [24] that regional trade agreements can support the WTO's multilateral trading system, actually it seems that they compete with the WTO. The mere fact of regional trade agreements means the absence of uniform rules for world trade – the primary goal of the WTO. Blocking work of the main body of the WTO disputes settlement system – The Appellate Body – led to the emergence of proposals for the transfer of the consideration of trade disputes from the multilateral system to the system of bilateral trade agreements [25], thereby weakening the position of less powerful countries, leaving them face to face with stronger states.

In addition, along with the reluctance to take part in the processes of regionalization, one should take into account the possibility of an intention to leave the integration organization in case of some dissatisfaction with its functioning. Such a right, as well as the refusal to participate in further processes of regional integration, belongs to the status of the state irrespective of its economic and military power.

Clearly, any regional organization is initially based on the concept of the nation-state and then on the elaborated concept of the regional state, the sovereignty of which is derived from the sovereignty of the nation-states. Consequently, with the emergence of a regional state and its sovereignty, a new identity must emerge, which will replace the identities of the nation-states, and the aim of the regional state is to secure the interests of that new identity,

There is no need to prove that the most advanced integration bloc in the world, the EU, which has a well-developed system of supranational authorities, although is quite close to becoming the regional state and actually is approaching the status of a full-fledged federation,

nevertheless has not been considered a regional state yet. In fact, the concept of a common identity, "European", for EU citizens of 28 countries has not appeared yet. Finally, Brexit and the euro area demonstrate that the EU ensures the rights of its member-states, the interests of which might conflict with those of the EU taken as a whole.

Thus, it is obvious that the globalization processes have reinforced positive and negative transformations on all the levels of the world economy but the main objective is to find the way to build on their advantages for the benefit of all the countries and regions of the world.

3 Sustainable development of regions from global perspective

Modern regionalism assumes the existence of four levels. The lower (local) level is the cross-border regional associations formed by the border territorial-administrative units of the neighboring countries, which create the so-called natural economic spaces.

At the local level, the most active interstate cooperation in the 1980-1990s was observed in Europe and East Asia. In Europe, cooperative associations emerged within the EU as a complement to subregional integration and as a means of deepening and optimizing it. The legal basis for these processes was the European (Madrid) Framework Convention on Transfrontier Co-operation between Territorial Communities which was adopted in 1989. By the end of the 1990s, there were more than 30 local cooperative entities integrated in Europe under the Border Regions Work Program. In Pacific Asia, the creation of local integration spaces (zones of economic growth) was in line with traditional for this part of the world non-institutional integration. Successful local economic cooperation projects include the Southern China Triangle (SCT), which includes the southern provinces of Guangdong and Fujian, Hong Kong and Taiwan.

The second level of modern regionalism is the most widespread category of regional integration organizations. The sub-regional entities represent different by the number of members groupings in one sub-regional zone. For example, in Europe – EFTA, in Latin America – MERCOSUR, in Africa – ECOWAS, etc.

The third, higher level of regionalism is formed by common regional economic groupings of a particular macro-region, such as the EU, ASEAN.

The example of the fourth level of regionalism is APEC as a transregional organization [4].

Classical theories of international cooperation and integration are rationalist and state-centered. Powerful states facilitate the emergence of regionalism in pursuit of economic and geopolitical interests. The United States, China, Russia, South Africa or Nigeria supported and engaged in region-building in order to strengthen military alliances, promote stability in neighboring countries, or secure access to new markets, cheap labour, water and energy resources [26]. So, the interregionalisation and trasregionalisation processes, along with the regionalization processes, are interrelated with the globalization processes as well.

At the same time transregional cooperation is promoted primarily by political factors, such as the wish of some states to play a greater role in global governance [27]. For example, the problem of strengthening two competitive blocs – Regional Comprehensive Economic Partnership and Transatlantic Trade and Investment Partnership in which China and the USA are trying to push their interests forward – may illustrate the point (some indicators are given in table 3).

Table 3. Regional comprehensive economic partnership and transatlantic trade and investment partnership.

Indicators	RCEP	TTIP
Population, mln, 2017	3604	838
GDP, mln dollars, 2015	22712154	33993080
Merchandise exports, mln dollars, 2017	5418089	7446853
Merchandise imports, mln dollars, 2017	4968072	8212786

Based on *UNCTAD Handbook of Statistics 2016, 2018.*

Practically, the current development of the interrelation between regionalization and globalization in the world economy indicates that various types of integration groups are being established (table 2), and the prospects of the two above-mentioned transregional organizations (table 3) are on the agenda, but it is doubtful that the integration organizations will become regional states in the near future.

To support this conclusion, let us see the dynamics of the most important economic indicator, GDP, presented in tables 4 and 5, which characterizes the development of the United States, the developed European countries (nearly the same compostion as that of the EU-28), and China during the period of 1980-2018.

Table 4. Dynamics of nominal GDP of the USA, Developed economies of Europe and China, mln dollars, 1980-2018.

	1980	1990	2000
World	12273690	22951417	33299310
USA	2877139	6010634	10347349
Developed economies: Europe	4081450	7930384	9271785
China	302943	396562	1208915

	2005	2010	2013	2014
World	47264846	65644956	76176342	78037088
USA	13177635	15062761	16765686	17451747
Developed economies: Europe	15068071	17986496	19231169	19755060
China	2291432	6005388	9518402	10430590

	2015	2016	2017	2018
World	74752058	76365009	80452800	85323228
USA	17925253	18664478	19490088	20600434
Developed economies: Europe	17165290	17361225	18415260	19899297
China	11156254	11386440	12020250	13605485

Source: *UNCTAD Handbook of Statistics 2016-2019.*

As we can see (tables 5 and 6), since the 2000s China has begun to catch up with the United States and the

developed European countries. It is necessary to underline that China transformed itself during the analyzed period from a weak developing economy into one of the three economic and political centers of the world.

Table 5. Dynamics of nominal GDP share of the USA, Developed economies of Europe and China, %, 1980-2018.

		1980	1990	2000	2005	2010	2013
1	**USA**	23,44	26,18	31,07	27,88	22,95	22,01
2	**Developed economies: Europe**	33,25	34,55	27,84	31,88	27,39	25,25
3	**China**	2,47	1,73	3,63	4,85	9,15	12,49
4	**1+2**	56,69	60,73	58,91	59,76	50,34	47,26
5	**3/1+2, %**	4,35	2,85	6,16	8,12	18,18	26,43

		2014	2015	2016	2017	2018
1	**USA**	22,36	23,98	24,44	24,23	24,14
2	**Developed economies: Europe**	25,31	22,96	22,73	22,89	23,32
3	**China**	13,37	14,92	14,91	14,94	15,95
4	**1+2**	47,67	46,94	47,17	47,12	47,46
5	**3/1+2, %**	28,05	31,79	31,61	31,71	33,61

Based on *UNCTAD Handbook of Statistics 2016-2019.*

Table 6. Per capita GDP of the USA, Developed economies of Europe and China in mln dollars, 1980-2018.

		1980	1990	2000	2005	2010	2013
1	**USA**	12355	23436	36078	43924	48018	52241
2	**Developed economies: Europe**	8838	16696	18522	29620	34763	36976
3	**China**	310	343	952	1755	4478	6986
4	**3/1, %**	2,5	1,46	2,64	4	9,33	13,37
5	**3/2, %**	3,5	2,05	5,14	5,93	12,88	18.89

		2014	2015	2016	2017	2018
1	**USA**	53990	55059	57253	59421	62380
2	**Developed economies: Europe**	37939	32924	33069	35010	37645
3	**3. China**	7617	8107	8110	8525	9530
4	**3/1, %**	14,11	14,72	14,17	14,35	15,28
5	**3/2, %**	20,08	24,62	24,52	24,35	25,32

Based on *UNCTAD Handbook of Statistics 2016-2019.*

It should be mentioned that on the background of negative impact of the world financial crisis of 2008-2010 China has proven to be one of the stable engines of globalization. Of course, the data shows that China's progress is impressive, but, in our opinion, it is hard to believe that China can be viewed as real competitor to the USA or the EU, especially if we pay attention to the dynamics of the per capita GDP as important socio-economic indicator shown in table 6. Nevertheless, only due to the People's Republic of China the center of world progress started shifting from North America and Western Europe to the Asia Pacific Region.

We should take into account that China's foreign policy is aimed at achieving the status of a superstate until the middle of the 21st century, and it looks like its global strategy "One belt, one road" will contribute to strengthening the position not only in Asia, but also in Europe and Africa. Under the conditions, it seems logical to expect both China and the USA to do their best in deepening integration ties with the EU-28 with the purpose of making their best for more effective functioning of their corresponding integration initiatives and/or establishing free trade areas (e.g., New Silk Road and Transatlatic Trade and Investment Partnership) but the EU will have to think carefully since it is challenging to take part it both integration organizations, expecially when China strongly supports free trade while the USA is focused on protectionism.

It's worth stressing that China is working at improving its trade ties (table 7) and is concluding as many free trade agreements as possible with various countries.

Table 7. Exports and imports of goods of China (100 mln US dollars).

Years	Export	Import	Balance
1978	97,5	108,9	-11,4
1980	181,2	200,2	-19,0
1985	273,5	422,5	-149,0
1990	620,90	533,50	87,4
1995	1487,8	1320,8	167,0
2000	2492,0	2250,9	241,10
2005	7619,50	6599,5	1020,0
2010	15777,5	13962,4	1815,1
2011	18983,8	17434,8	1549,0
2012	20487,1	18184,1	2303,1
2013	22090,0	19499,9	2590,1
2014	23422,9	19592,3	3830,6
2015	22734,7	16795,6	5939,0
2016	20976,3	15879,3	5097,1
2017	22633,5	18437,9	4195,5
2018	24866,8	21357,3	3509,5

Source: China Statistical Yearbook 2019. Foreign Trade and Economic Cooperation.11-2 Total Value of Imports and Exports of Goods. www.stats.gov.cn/tjsj/ndsj/2019/indexeh.htm

In general, experts continue to discuss the expansion of existing regional arrangements to include more countries, as well as the broadening and deepening of existing trade and investment liberalisation provisions.

In our opinion, the development path of all the regional integration aspirations should be used as a means of the consolidation of the world economy and should be directed in order to contribute to the balanced and sustainable development not only of the regions, but of the world [29]. On the one hand, scholars try to see sustainable future relating to the globalization level of world development while, on the other hand, many scientists innovate within the field of international studies, focusing on nation-state as the primary actor. We have shown the importance of all the three levels, paying special attention to the regional one. We agree with the specialists in world regions, who see the global phenomena through the lenses of myriad localities [30].

To conclude, the regional level plays significant role in supporting the balanced structure of the complex system of the world economy and is the key for the world's future sustainable functioning.

Conclusions

Thus, the advancement of globalization processes results from the whole set of interactions of the integration processes, mainly at the regional level, and can occur in different ways, there are different scenarios for the development of global processes. Of fundamental importance here is the fact that at the global level, in order to preserve unity in diversity, a multipolar rather than a unipolar system must be formed to ensure the sustainable future for regions and the world.

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Sustainable competitive innovative development and economic security of enterprises under unstable conditions: mutual dependency and influence

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Abstract. The paper reveals interrelations between the concepts "economic security", "economic sustainability", "development" and "competitiveness" of an enterprise. Based on their consideration, the paper enhances theoretical and methodological principles of establishing competitive innovation development and economic security of an enterprise. Unlike the existing ones, these principles provide for not only alternativeness but also equal significance when choosing between achievement of high levels of competitiveness, development and economic security. Application of the elaborated suggestions enables more objective formation of the policy of management of an enterprise's innovation development under unstable conditions considering the industrial field and the market position of the enterprise. It is proven that essential elements of enterprises' sustainable development include innovative activity, production provision, export of science-intensive products and development of high technology services, this providing for efficient levels of enterprises' economic security and competitiveness. Under conditions of uncertainty, there are some basic functions of an enterprise aimed at enhancing its competitiveness and economic security including the following: achieving the optimal level of an enterprise's resulting indicators and efficient "income-risk" ratio, innovative activity, ensuring the quality of an enterprise's intellectual capital, environmental safety and meeting required social standards.

1 Introduction

1.1 Problem statement and its topicality substantiation

Establishment of efficient levels of an enterprise's economic security is an essential element of enterprise management as a whole under current unstable macroeconomic conditions. Management of economic security is becoming a priority along with enterprises' competitiveness and financial stability and forms the foundation for their stable innovative development. The basic stage of forming an enterprise's stable economic development involves setting up an efficient permanently functioning system that includes management of competitiveness, economic security, economic sustainability, and innovation and investment attractiveness. Considering this, there are some unsolved problems concerning determination of these basic definitions and their interrelation.

1.2 Analysis of the latest researches and publications

A lot of scholars are engaged in solving the problems of an enterprise's sustainable development, its economic security and competitiveness. [1-3, 9, 10, 18-35] deal with some issues of forming, controlling and assessing levels of economic security.

Competitiveness, its types and specific features, methods of its assessment and forecasting as well as scientific approaches to determining interrelation between economic security and competitiveness are under detailed consideration in [4-8, 11-17, 36, 38, 42-44]. It should be noted that foreign researches mostly deal with issues of competitive intelligence and provision of competitiveness of enterprises [45-47]. [39-44] also touch upon the issues of sustainable development on all economic levels including sustainable innovative development. At that, connection of innovations with the level of economic security of enterprises remains unstudied. Analysis of foreign researches into economic security show that there are two most widely spread conceptions – the Anglo-Saxon and the Asian ones. The former focuses on economic security of households and an individual and is actively popularized in the United States of America [48; 49]. The latter is based on the macroeconomic approach to provision of national economic security. Representatives of some Eastern European schools of thought are among the followers of this conception [50]. Since the 1990s, the third conception has been developing at a rapid rate. It focuses on actualization of economic

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security of enterprises considering macroeconomic factors. Its fast development started in post-Soviet countries [50; 51] which is most probably conditioned by their instable economies resulted in a great number of bankruptcies. Thus, there are some issues left unsolved concerning conditions, under which economic security, competitiveness, sustainability and development influence one another and become identical under unstable economic conditions. For this reason, investigations into conditions determining availability and direction of interrelation between economic security and the mentioned categories are gaining topicality.

2 Results

Let us consider interrelation between economic security and competitiveness of an enterprise. The conducted analysis of available scientific investigations into this issue enables the following three directions (Fig. 1).

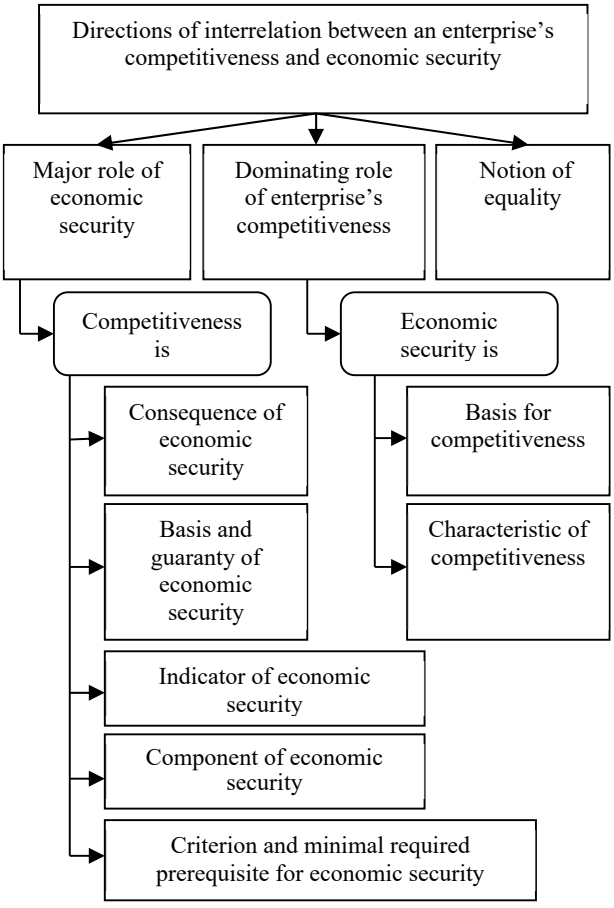

Fig. 1. Directions of interrelation in the conceptual pair "competitiveness-economic security".

In the first direction of investigations, economic security plays a major role. Meanwhile, the content of the secondary role of competitiveness varies.

In particular, the monograph authors [1] consider the difference of notions under study as time characteristics because competitiveness is associated with short-term prospects, while economic security is characterized by an enterprise's ability to function in an efficient and secure manner both at present and in future in accordance with its mission and goals conformed with stages of its life cycle. Within the first approach, the scholars define competitiveness as a notion of secondary importance in terms of economic security and consider it as:

- a consequence of economic security. In O. M. Kuzmenko's opinion, competitiveness is a direct consequence of an enterprise's strong economic security, which is "one of the essential indicators of a stable market position and enables maintaining it for some period of time" (Here and after the translation is ours). The researcher also thinks that interrelation between an enterprise's economic security and its competitiveness is direct and linear, i.e. high competitiveness is a guarantee of its strong economic security (or perception of the latter in such a way) [3];
- the basis and guarantee of economic security. This idea is expressed by K. A. Svekla and I. O. Kuznetsova who indicate that an enterprise's competitiveness is the basis for enhancing economic security and a guarantee of its strong formation enabling an enterprise to preserve its stable market positions [4]. The researchers highlight the potential of successful economic security to enhance business sustainability and competitiveness as a whole [4];
- an indicator of economic security. N. M. Pylypenko describes high competitiveness as an indicator of economic security [5]. According to the Academic Explanatory Dictionary, an indicator is the reason for and a driving force of a process that determines its character or its individual constraints [6].
- a component of economic security. O. O. Falchenko and N. B. Tokar define competitiveness as a component of economic security, which characterizes the degree of conformity of internal potentials of an enterprise's development with its external ones generated by the market environment [7];
- a criterion and a minimal required prerequisite for economic security. A. A. Sadiekov and T. B. Khlevytska consider competitiveness a criterion and a minimal required prerequisite of an enterprise's economic security that enhances its sustainable development [8].

According to M. V. Chorna, provision of an enterprise's economic security should be aimed at achieving basic target indicators of its activity including the required level of competitiveness and stable functioning of an economic entity; facilitation of owners' (shareholders') wellbeing, an enterprise's advance; an ability to survive, i.e. provision of sustainability and accomplishment of economic potential targets; harmonization of social and economic interests [9]. Z. Shershniova investigates into adaptability as an enterprise's competitive advantage and defines it as a result of an enterprise's efficient activity with a created and efficient economic security system [10].

According to the second approach, competitiveness plays a dominating role in the "economic security-competitiveness" conceptual pair. As L. M. Khrystenko and A. I. Mykhailichenko think, the dominating role of competitiveness goes without saying, while economic security is its obligatory foundation [11]. I. H. Rzaiev considers competitiveness within the framework of an enterprise's economic security, which is only a

characteristic of an enterprise's competitive level that guarantees relevant efficiency of an economic entity's functioning that conditions economic security on the economic field level, facilitates indicators of assets, expenditures and financial results [12]. It should be noted that in practice, in Japan, in particular, there is a government strategy of enhancing competitiveness of an economic field as a whole on the world markets, which provides for seven basic strategies of its implementation, development of business economic security being the fifth one [13]. According to the third approach, interrelation of concepts "economic security-competitiveness" is mutually conditioned and neither of them is considered prevailing or secondary. As O. M. Tkachenko indicates, to provide economic security, it is expedient to solve the problem of competitiveness and, vice versa, to achieve high competitiveness, it is necessary to enhance its economic security [14].

It is also worth noting that there are cases when an author or authors express contradictory ideas within the same paper. For instance:

- L. M. Khrystenko and A. I. Mykhailichenko indicate that except for the above-mentioned, an enterprise that does not ensure its own economic security is unable to use its competitive advantages and is heading for their loss [11];
- O. M. Tkachenko identifies an enterprise's competitiveness as the basis of its economic security and a guarantee of its strong development that enables an enterprise to maintain its stable market positions [14].

Use of the concept "development" in the definitions of both economic security and competitiveness of the enterprise is another block of investigations (Fig. 2).

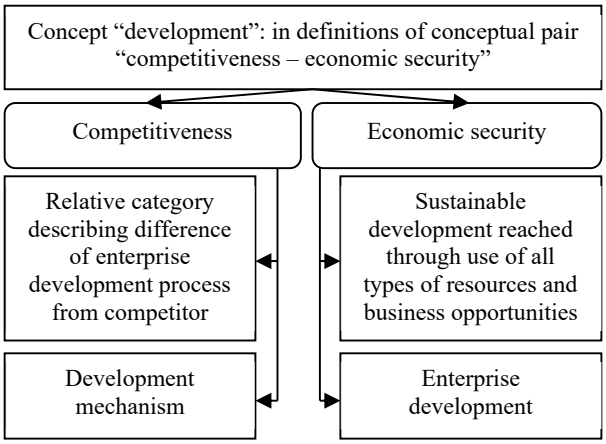

Fig. 2. The general concept "development" in definitions of the conceptual pair: competitiveness – economic security of an enterprise.

The principal difference between the definitions of competitiveness of an enterprise and those of economic security contrasted to them in Fig. 2 lies in the fact that the former mostly focus on comparison of the enterprise with its competitor while in the definitions of economic security enterprise development is considered separately from other economic entities and, moreover, economic security itself is identified with competitiveness. The analyzed definition treated in terms of enterprise development enable concluding that essentiality of the concept of economic security of an enterprise is deeper than its competitiveness. Besides, analysis of the literature, including [18 – 20], enables differentiating this trend in connection with the concepts of development and economic security where economic security is the same as development, a state of development or an ability to develop. We suggest the name "complete identification"

In most scientific works that consider the concept "enterprise development", the latter results from a certain condition of an enterprise or efficient use of its resources (Fig. 3).

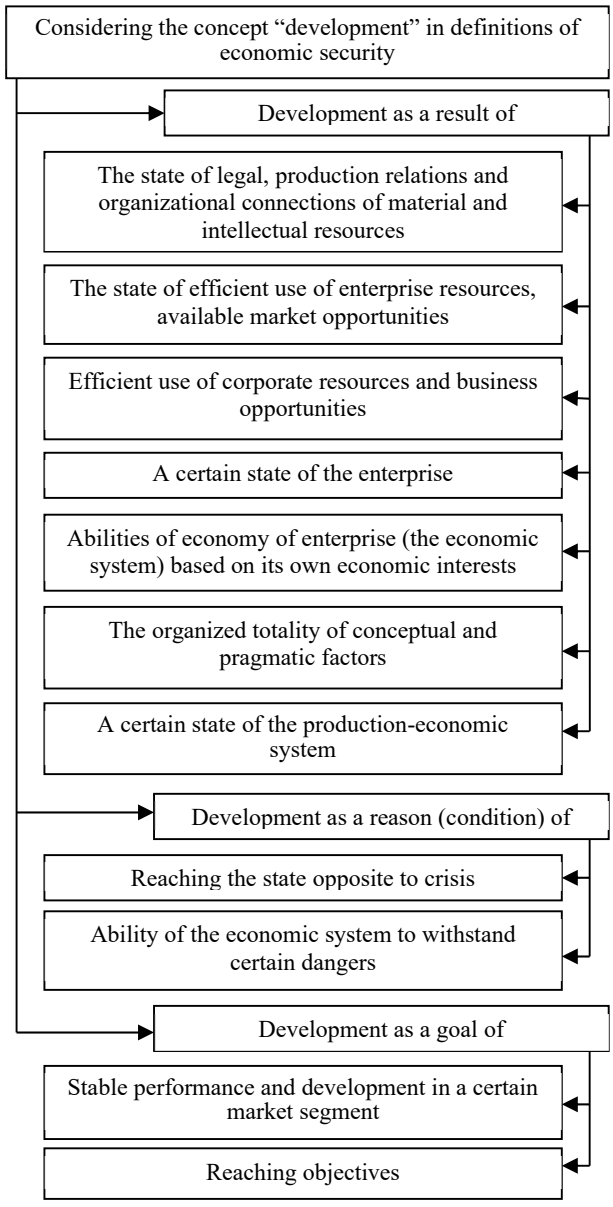

Fig. 3. Development roles in various definitions of economic security of the enterprise).

Let us consider the work by Ye. O. Didenko where the process of managing economic security is identified with the strategy of secure development of an enterprise which is a complex program of actions determining priority trends of economic activities when threats to the enterprise emerge as well as necessary resources to prevent them or minimize their impacts [32].

However, the majority of researchers dealing with economic security of an enterprise assign its development to objectives of the security provision even if they do not mention this in the definition. For instance, according to N. P. Sysolina, in management of economic security there are singled out contours of operating management characterized just as resistance to already emerged threats; tactical management characterized by the ability of adaptation and strategic management noted for by the ability of continuous development [33].

There is no consensus among the researchers on which of the concepts under analysis is primary and which is secondary; whether development is the objective of economic security or the enterprise can only develop in conditions of economic security. The only common thing is that most researchers recognize the relation between the concepts and call it the cause-and-effect relation. Several works attempt to settle these problems. However, analysis of these works shows contradiction and ambiguity of the answers. The critical review of specialized literature enables us to identify bipolarity of scholars' views on the relation between the concepts "enterprise development" and "economic security" – some scholars consider it linear, others call it direct [21–33]. On the contrary, in [34] (with the reference to M. O. Dzhaman and G. O. Goncharova), the categories "security" and "development" are called equal and independent. Nevertheless, we believe that interinfluence of development and security does not allow stating principal absence of relations between them even in case of the equal approach. Absence of relations may occur in the short-term period. The conducted research enables systematizing current ideas of relations between development and economic security into four directions (Fig. 4).

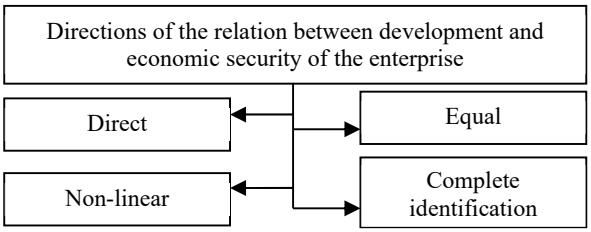

Fig. 4. Directions of the relation between development and economic security.

We believe that all the four directions are not mutually exclusive. On the contrary, all scholars are right: relations between economic security and development may be direct, non-linear, complete identification and equal under certain goals, conditions and circumstances. Comparison of the essence of the concept of economic sustainability with that of economic security elicits issues for discussion. Thus, in [35] the definitions of enterprise economic security contain features that do not have analogues in the term "enterprise economic sustainability". Along with that, there exists an opposite situation when the definitions of "enterprise economic security" contain specific characteristics, e.g. the concept "equilibrium" ("equilibrium state"). For instance, Yu. A. Simekh characterizes economic sustainability of an enterprise as its potential to return to the state of equilibrium in which it possesses positive dynamics of performance or stay within the established boundaries [36]. However, some scholars find this question debatable. Thus, according to the systems theory, equilibrium is a separate case of system sustainability which indicates inexpediency of identifying it with equilibrium or the ability to return to it [37]. So, analysis of scientific literature enables us to assert that between the concepts under study there are more similarities than differences. On the basis of the conducted research, we suggest common approaches to understanding the essence of the concepts "enterprise economic security" and "enterprise economic sustainability" underlain by various classification features: static, dynamic (process); resource-functional, adaptive-developmental, supportive goal-oriented; complex (mixed). At that, different approaches to enterprise economic security are harmonization, guarantee and protective, those to enterprise economic security are equilibrium (which is debatable) and renewable (reproducing). We believe that enterprise economic sustainability is of triple nature as is economic security. It is characterized simultaneously as a state, a process and a resource of an enterprise. At that, having common resource provision and business-processes of provision and support, economic security may be identical to economic sustainability of the enterprise. So, four possible situations can be elicited (Fig. 5).

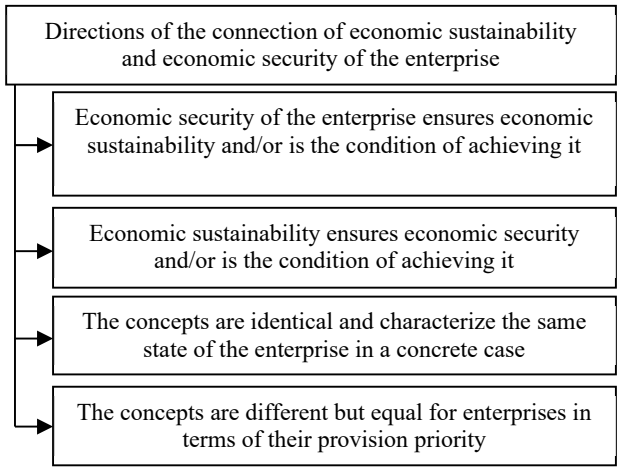

Fig. 5. Directions of the connection of economic sustainability and economic security of the enterprise.

Enterprise being in one of the mentioned situations depends on the set goals, performance conditions, multivariance of internal and external environments and availability of resources (Fig. 6).

Economic instability is an important complicating exogenous factor, the impact of which must first be offset in the process of managing a competitive innovative development of the enterprise. The red line in most scientists' researches defines component aspects of such leveling.

At the first stage, it is necessary to determine directions and vectors of influence of such conditions on the basic financial and economic results of an enterprise

(its market capitalization, capitalization rates, absolute and relative indicators of economic efficiency, owners' income levels, quality of profit, etc.).

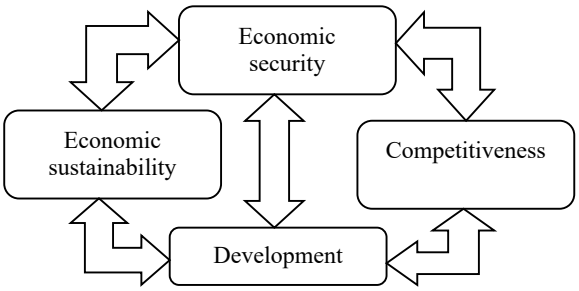

Fig. 6. Relation of economic security with key concepts: competitiveness, development, sustainability.

The second stage of counteracting such an impact is to calculate general, local and partial indicators of assessment and analysis of the economic activity of the enterprise. In doing so, both the classical methodological approaches of such analysis and the specific ones (for example, methods of measuring the probability of bankruptcy) are used.

The third stage involves development of a system of organizational and economic steps to ensure economic security under corresponding conditions. This kind of system represents a well-run mechanism comprising such basic components as updating the system goals, setting aims and objectives, determining principal tasks of leveling uncertainty of the environment, singling out subjects and objects of the mechanism, establishing interrelations between the subjects and objects, developing managerial measures and priority of functional stages, developing proposals about controlling and coordinating managerial processes.

It should be noted that focus on innovation is an important element of sustainable development of the enterprise. For instance, at enterprises of developed countries sustainable development is ensured at the expense of manufacturing and export of science-intensive products. The countries are gradually closing down purely industrial production and developing high-tech intellectual services. One can state that, unlike in Ukraine, development of enterprises in these countries is aimed at increasing rates of the scientific and technological progress, building up intellectual capital. All the mentioned is a guarantee of establishing the appropriate level of economic security and competitiveness of enterprises. So, sustainable development of enterprises should be based on application of radically new progressive technologies, managerial systems, intellectualization and informatization of production, environmental safety, etc.

Under conditions of uncertainty the following basic functions of the enterprise aimed at ensuring competitiveness and long-term economic security can be singled out:
a) achievement of an optimal level of resulting indicators of enterprise performance (the increased market value of the enterprise, increased owners' incomes, increased economic efficiency);
b) achievement of an optimal "income-risk" ratio;
c) innovativeness (one of the key functions of the enterprise which enables the enterprise to ensure maintenance of its long-term economic efficiency and competitiveness at each stage of its life cycle through timely and reasonable implementation of innovations);
d) provision of quality of intellectual capital of the enterprise (quality of intellectual capital is closely connected with establishment of the innovation and information level of the enterprise. Increase of the level of intellectual capital quality is ensured through involvement of new knowledge on the basis of qualitative personnel recruiting (especially top-management of the enterprise));
e) provision of continuous environmental safety (environmental protection in conformity with basic requirements of environmental and green economy);
f) maintenance of the required level of social standards of the enterprise, etc.

Continuous monitoring of performing the above-mentioned functions is a prerequisite for reaching the optimal level of economic security of the enterprise. In addition, applying the suggested algorithm of leveling the instability, it is required to determine possible increase of the level of sustainable competitive innovation-oriented development.

3 Conclusions

Thus, in our opinion, correlation of the concepts of economic security – competitiveness depends on the enterprise capacity, specific character of functioning (necessity of licenses, permits, unique production, etc.) and an industrial field. For instance, small enterprises work in conditions close to perfect competition and, therefore, their competitiveness is top-priority to them as it underlies their economic security. Mining and metallurgical enterprises work in conditions of oligopoly and that is why the interrelations here are objective. For enterprises-monopolists, competitiveness plays a smaller part. Thus, sustainable competitive innovative development and economic security of enterprises under unstable conditions is an important task for top-management activities. Scientific novelty of the present paper consists in enhancement of theoretical and methodological principles of forming competitive innovation development and economic security of enterprises that will facilitate better management under conditions of uncertainty and instability. To achieve this, the article determines interrelations and interdependencies of corresponding economic definitions, suggests methodological approaches to leveling the negative influence of uncertainty and instability and emphasizes the necessity of innovative development.

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A methodological approach to the evaluation of the effectiveness of innovative projects

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Abstract. Ensuring the sustainable development of the economy depends to a large extent on the implementation of the innovative model, in which the innovation infrastructure plays a key role. The growing number of technoparks in Ukraine has increased the requirements for economic substantiations for decision-making regarding the expediency of implementing their innovative projects. The search for appropriate methods and approaches to project evaluation has determined the actuality of the research topic. The article summarizes the methods of evaluating innovative projects, identifies their advantages and disadvantages. Besides, it reveals the features of the evaluation of innovative projects of technoparks. The novelty of the work is the proposed methodological approach to the evaluation of the efficiency of innovative technopark projects, which takes into account the specifics of the Ukrainian legislation. The methodological approach is based on the generally accepted performance indicators in the world: Net Present Value, Profitability Index, Internal Rate of Return, and Payback Period. Special accounts of technology parks, their participants, and joint ventures are a separate element in the calculation formulas. The application of the proposed methodological approach will accelerate the process of selection of innovative projects and their implementation, activation of innovative activities, and the sustainable development of the state. The proposed methodological approach is tested in the evaluation of the innovative project of the technopark of the E. O. Paton Electric Welding Institute and confirmed the effectiveness of its implementation.

1 Introduction

Ensuring the sustainable development of the economy depends to a large extent on the implementation of the innovation model, in which the innovation infrastructure plays a key role. It provides strong links between the subjects of innovation and, through the realization of its innovative potential, promotes the transfer of knowledge and diffusion of technologies.

An acceptable form for this is any structure that has been tried and tested in the world, and that allows concentrating financial and material resources on innovative development.

The most widespread concept is the technopark concept of development. According to world data, in the developed countries of the world technological innovations implemented within the framework of the specified concept provide almost 50% of efficiency of the market economy, and the share of the latest technologies, innovative products, new approaches in the organization of production and the sphere of services accounts for 80% of GDP growth [1].

The main idea of technoparks is the commercialization of scientific research, the production of which is brought to commercial structures. The combination of interests of developers and consumers caused an increase in the number of science and technology parks in Ukraine, which, in turn, increased the requirements for economic substantiations of decisions on the expediency of implementing innovative projects.

The search for appropriate methods and approaches to project evaluation, based on the current state of the Ukrainian economy, determined the actuality of the research topic.

The purpose of this article is to propose a methodological approach to the evaluation of the efficiency of innovative technopark projects, which will take into account the specifics of the Ukrainian legislation and accelerate the process of selecting the most effective innovative projects for implementation.

2 Analysis of main achievements

Key aspects of economic development are now reoriented in the world. Resources and innovations became key elements in achieving national goals [2].

Prospects for economic development through innovative infrastructure are reviewed in the works of many authors. The development of innovative infrastructure is linked to the implementation of startups

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[3-4], with foreign direct investments [5]. Some scientists focus on the aspects of innovation resource management [6] and argue that ensuring sustainable economic development presupposes the application of different ways of the engagement of stakeholders, which will influence the outcome of the process and the ensuring of sustainability. In an innovation-driven world, collaboration between men of science and business is a prerequisite for sustainable economic growth [7]. The study discusses how different types of collaboration influence the effectiveness of new product development (NPD) [8].

The effectiveness of economic innovation positively correlates with the stability of innovation activity. This means that innovation goals in economics and sustainability can be achieved simultaneously [9].

The study [10] presents the application of an economic-probabilistic model for conducting risk analysis in technological innovation projects. The model integrates risk and economic analysis through quantifying the value as well as the probability of cash flow deviations, which leads to an economic-probabilistic analysis of expected returns. The importance of risk analysis in technological innovation projects is also emphasized in this study. [11].

During the implementation of investment projects with the use of innovations, considerable difficulties appear [12], namely, the determination of project expenses and their planning, as well as the expediency of their effectiveness considering the influence of risk factors. It is proposed to predict and control the cost of a project and its predicted effectiveness at each stage of the project life cycle. At that, it is important to evaluate the possible efficiency of the fluctuation range, which characterizes the degree of stability of the project effectiveness evaluation.

The study [13] is devoted to the examination of the relationship between an emphasis on innovations and relative economic effectiveness. In economic effectiveness management, the main focus is on reducing revenue-related expenses. This implies, not necessarily, reduction in expenses and also the utilization of the revenue that can be derived from investing in innovations. A wide range of methods for the evaluation of innovative projects and the problems of evaluating their effectiveness are reviewed in the works of [14-17]. The authors propose an approach with the use of net present value (NPV).

3 Research methods and results

The main regulations on the creation and functioning of Ukrainian technoparks are given in the Law of Ukraine "On the Special Regime for Innovation Activity of Technology Parks", No. 991-XIV from 16.07.1999 [18]. The importance of the development of their activity is also emphasized in the Draft Law of Ukraine "On Amendments to Some Legislative Acts of Ukraine on the Activity of Technology Parks", No. 0943 from 29.08.2019 [19].

In comparison with regular investment projects, the implementation of innovations has its fundamental features:

a) a higher degree of unknown parameters of the project (predicted results, terms of development and implementation, costs, revenues), which significantly reduces the reliability of the preliminary financial assessment of the project. This requires additional selection criteria based on the collection of a large amount of necessary information. Therefore, in parallel there is a definition of what kind of information you need to get in order not to perform additional work, which will lead to an increase in project costs;

b) focus on long-term results, requires more stringent requirements for forecasting and for accounting for the time factor;

c) the need to attract highly qualified scientific specialists who often work part-time. This requires a detailed development of the stages of the project;

d) the possibility of terminating the implementation of the project without significant expenditure of material resources (as, for example, this happens in the manufacturing sector, where, as a result of the impossibility of further financing, all kinds of long-term construction projects emerge, etc.);

e) a high probability of obtaining results that were not expected, but have potential commercial attractiveness. This enables to rely on the rapid diffusion of the project and potentially high profits.

The basis for the work of technoparks is the implementation of innovative projects, each of which requires appropriate funding. An innovation project is inherently an investment project, which is carried out to implement STP in the production and social sphere. Therefore, the most important problem that arises when organizing work on financing innovative projects is to determine their attractiveness to investors.

When choosing the most attractive innovative project, technoparks evaluate their production, financial, and economic capabilities. The market situation is analyzed; production capacities and product range, administrative, management, and scientific-technical staff of the company are carefully viewed. At that, a variety of decision-making methods – from subjective to objective, from intuitive and empirical to accurate – are used. In practice, mixed decision-making methods that are on the border of intuition and science are often used, or they are a combination of both, and form heuristic methods and models.

Technical and economic analysis of evaluating an innovative project that uses the whole set of indicators found a wide application. The advantage of this method is that the project is evaluated from different sides and in much detail. But this requires a large amount of information, which is usually not sufficient.

The very essence of economic tasks presupposes the use of many criteria. However, the selected project evaluation criteria can be controversial, and the known mathematical calculation methods allow determining the optimum only for one objective function. The development of a model that meets all the criteria is still very problematic.

Often the methods used in the evaluation of innovative projects are theoretically less accurate, but in practice more acceptable.

One method is to simply compare the advantages and disadvantages of separate project variants or a few projects. The effectiveness of this method is enhanced by applying a systematic approach to evaluation, that is when each variant (project) is evaluated against the whole set of criteria. The result is a complete list of advantages (+) and disadvantages (–) that are more convenient to show in a matrix form. The choice of variants (projects) can be made by the exclusion method. This method is quite simple but far from accurate, so it can be used only for approximate analysis.

In more complex cases that require detailed analysis, a scoring system is usually used. It helps to evaluate each criterion of the variant (project) according to a certain number of points. A point scale is quite differentiated and allows to evaluate the similar parameters of different projects as well as the different parameters of the same project. In modern conditions, up to 30 project selection criteria are used in US firms. The selection is based on a system of scoring the proposed criteria considering the weighting factors of each of them.

The advantage of the scoring method is that it allows quantifying each criterion and to evaluate the project according to the total score. However, the real value of such conclusions depends on the accuracy of the scoring, intuitively determined. Therefore, in practice, during the decision-making process, besides the scoring system, the cost comparison method is used.

The cost comparison method has a more versatile application because the ultimate conclusion here is based on maximizing profit. The assessment is based on the comparison of investments and future cash inflows. This approach is particularly important when implementing strategic projects, and each innovative project is inherently strategic.

The estimation of the potential profitability of a project is a rather difficult task, but the need and importance of such a task is confirmed by international practice.

Under market conditions, financial and economic factors of attractiveness play a significant role. The greatest attention is paid to the indicators of the absolute efficiency of the projects, which make it possible to evaluate each innovative project separately without solving the problem of reallocation of resources between alternative variants. For technology parks, such an assessment is of particular importance. At the economic substantiation of the technopark project, the following indicators in its business plan are used: payback, net discounted cash inflow, internal rate of return.

Absolute efficiency is evaluated according to the following criteria of the movement of financial flows (expenses and incomes), accepted worldwide:

1) Net Present Value;
2) Profitability Index;
3) Internal Rate of Return;
4) Payback Period.

When evaluating innovative projects, the net present value indicator is one of the main ones. The essence of the method is to calculate the net present value (NPV), which is defined as the difference between the present value of future cash inflows and the present value of investment in the project:

$$NPV = \sum_{i=0}^{n} \frac{CI_i - In_i}{(1+d)^i} \quad (1)$$

where CI_i – annual cash inflows in the i-th year;
In_i – amount of investment in an innovative project in the i-th year;
d – discount rate;
n – project implementation time.

When forecasting annual cash inflows, it is necessary to take into account all their types – both production and non-production – which are related to the project implementation. First of all, it is net income and depreciation. However, if the proceeds are planned to be in the form of an equipment liquidation value or the release of a portion of current assets, they should be taken as income for the relevant periods. Therefore, for the ordinary enterprise the calculation of annual cash inflows will be made by the formula:

$$CI_i = NP_i + A_i + OI_i \quad (2)$$

where CI_i – net income in the i-th period;
A_i – depreciation in the i-th period;
OI_i – other cash inflows in the i-th period.

In such case formula (1) will take the following form:

$$NPV = \sum_{i=0}^{n} \frac{(NP_i + A_i + OI_i) - In_i}{(1+d)^i} \quad (3)$$

By formula (3) it is possible to evaluate any investment project. However, not every investment project is inherently innovative. After reading the Ukrainian legislation, it turned out that there are peculiarities of evaluating an innovative project by a technology park.

The Law of Ukraine "On the Special Regime of Innovative Activity of Technology Parks" [18] provides some privileges for technology parks. For the implementation of technology park projects, the state provides technology parks, their participants and joint ventures that implement technology park projects with targeted subsidies in the amount of import duties, calculated following the Customs Law of Ukraine, when new equipment and component parts, as well as materials that are not manufactured in Ukraine, are imported into Ukraine for the implementation of technology park projects.

These import duties are credited to the special accounts of technology parks, their participants and joint ventures. At that 50% of import duties are credited to the special accounts of the participants of the technology parks and joint ventures that are implementing technology parks projects, and the remaining 50% of import duties are credited to the special account of the

governing body of a certain technology park. Besides, during the implementation of technology park projects technology parks, their participants and joint ventures are allowed to accelerate the depreciation of fixed assets involved in the project of the technology park, and the annual 20% rate of the accelerated depreciation of the fixed assets of groups 3 and 4 is set. At that, the depreciation of group 3 fixed assets involved in the technology park project is held until the carrying amount of the group is zero.

Therefore, for technology parks, annual cash inflows will be calculated by the formula which is somewhat different from formula (2):

$$CI_i = NP_i + A_i + SA(P)_i + SA(TP)_i + OI_i, \qquad (4)$$

where $SA(P)_i$ – funds that are credited to the special account of participants of technology parks and joint ventures that are implementing projects of technology parks in the *i*-th period;

$SA(TP)_i$ – funds that are credited to the special account of the governing body of a certain technology park in the *i*-th period.

NPV will be calculated by the following formula:

$$NPV = \sum_{i=0}^{n} \frac{(NP_i + A_i + SA(P)_i + SA(TP)_i + OI_i) - In_i}{(1+d)^i} \qquad (5)$$

If the present value of future cash inflows from the project is higher than its original cost or discounted value over several years, then the project should be implemented, and vice versa, if the present cost is lower than the original cost, the project should be rejected because the investor will lose money from the implementation of this project. In other words, the net present value of the approved project should be zero or positive ($NPV \geq 0$) and the net present value of the rejected project should be negative ($NPV < 0$).

The profitability index (*Ip*) is a method that compares the present value of future incomes with initial investments, that is, it's the ratio of the present value of cash inflows to investments. This criterion characterizes income per unit of expenses. It is the best one when arranging independent projects to create an optimal portfolio in the case of a tight budget. In this case, projects with the highest profitability index should be preferred.

The profitability index is calculated by the formula:

$$Ip = \sum_{i=0}^{n} \frac{CI_i}{(1+d)^i} \div \sum_{i=0}^{n} \frac{In_i}{(1+d)^i} \qquad (6)$$

Taking into account formula (6), the profitability index of an innovative project, when executed by a technology park, will be calculated by the following formula:

$$Ip = \frac{\sum_{i=0}^{n} \frac{(NP_i + A_i + SA(P)_i + SA(TP)_i + OI_i)}{(1+d)^i}}{\sum_{i=0}^{n} \frac{In_i}{(1+d)^i}} \qquad (7)$$

The profitability index, in contrast to the net present value, is a relative value. In the numerator of formula (7) the value of income before the beginning of the innovation selling process is specified, and in the denominator the value of investments in innovations discounted before the beginning of the investment process is given. In other words, the two parts of the payment stream are compared: income and investment.

The profitability index is closely linked to the integral effect of implementing an innovative project that acts as a net present value (*NPV*). If $NPV > 0$, then $Ip > 1$ and the project is accepted. Conversely, if $NPV < 0$, then $Ip < 1$, and the project is considered ineffective.

Internal rate of return (*IRR*) is a very popular metric when evaluating the expediency of investing. It is the discount rate at which discounted income over a specified period of time is equated with innovative investments. In this case, the income and expenses of the innovation project are determined by bringing it to the estimated moment.

In other words, the internal rate of return characterizes the level of profitability of a certain innovation project through a discount rate, at which the future value of the income from innovation is brought to the present value of the investments.

Abroad, the calculation of the internal rate of return is often used as a first step in the quantitative analysis of investments. For further analysis innovative projects, in which the *IRR* is 15-20%, are chosen. The calculated *IRR* value is compared with the required rate of return for an investor. An innovative solution can be considered only when the *IRR* value is not less than the investor needs.

If the innovative project is fully financed by a bank loan, the *IRR* value indicates the upper limit of the permissible level of bank interest rate, the excess of which renders the project economically inefficient. If the project is financed from other sources, the lower IRR value corresponds to the cost of the advanced capital, which can be calculated as the arithmetic weighted average of the payments for the use of the advanced capital.

Practical use of this method is reduced to a successive iteration, by which the discount factor which will ensure equality $NPV = 0$ is found, or:

$$\sum_{i=0}^{n} \frac{CI_i - In_i}{(1+IRR)^i} = 0 \qquad (8)$$

For technology parks, formula (8) in view of formula (7) will have the following form:

$$\sum_{i=0}^{n} \frac{(NP_i + A_i + SA(P)_i + SA(TP)_i + OI_i)}{(1+IRR)^i} - \\ - \sum_{i=0}^{n} \frac{In_i}{(1+IRR)^i} = 0 \qquad (9)$$

Using the calculations (or tables), two discount rates are selected so that in the interval (d_1, d_2) the $NPV = f(d)$

function would change its value from "+" to "–" ($d_2 > d_1$). Thus, at this interval, there is a root of the equation $f(d) = 0$. To do this, use the formula:

$$IRR = d_1 + \frac{NPV(d_1)}{NPV(d_1) - NPV(d_2)} \cdot (d_2 - d_1) \quad (10)$$

where d_1 – value of the discount rate at which $f(d) > 0$;
d_2 – value of the discount rate at which $f(d) < 0$.

The payback period (T) is one of the most common indicators of evaluating the effectiveness of investments in an innovative project. In contrast to the indicators used in domestic practice, the payback period of capital investments is not based on profit but cash flow, bringing investment into innovation and cash flow to its original value.

In a market economy investing is closely linked with significant risk and the longer the payback period, the greater this risk. Market conditions and prices can change significantly during this time. This is especially true for industries with high tempo of STP, when the emergence of new technologies or products is rapidly devaluing previous investments.

The payback period is used when there is no certainty that an innovative project will be implemented and so the owner of funds does not risk entrusting the investment for a long period of time.

The payback period of the project is determined according to preliminary calculations of net cash inflows (CI) and net present value (NPV):

$$T = p + NPV_p / CI_{p+1}, \quad (11)$$

where p – last year when $NPV < 0$;

NPV_p – net present value in the p-th year (without sign "–");

CI_{p+1} – value of net cash inflows in the $(p + 1)$ year;

International practice has established that the payback period of the innovation must not exceed five years, which should be accepted in the calculations.

It's worth to say that during the analysis of alternative projects, the considered criteria may contradict each other, that is, a project which is acceptable by one criterion may be rejected by another.

In case of contradiction, it is recommended to take the net present value criterion as the basis.

Having considered the basic methods of the evaluation of innovative projects by a technopark, let's use them in practice. The technology park of the E. O. Paton Electric Welding Institute is in the first turn preparing for the implementation of an innovative project on the creation of new technology and equipment for semi-automatic welding, which presupposes the production of new lightweight panels for space and rocket, aeronautical, shipbuilding and other industries. The term of the implementation of this innovative project is 5 years.

All necessary data for the calculation is given in Table 1.

It is estimated that the investment in the project will amount to 80 million UAH and will be made before the project implementation is started. Capital investment will be done in the form of equipment belonging to the third group of fixed assets. For the implementation of the project, they anticipate the procurement of component parts and materials not produced in Ukraine with their average import duty amounting to 2% of anticipated current expenses.

Table 1. Results of the implementation of the innovative project by the technopark, thousand UAH

Indicators	Years				
	1	*2*	*3*	*4*	*5*
Sales revenue	51680	52160	57600	58720	60400
Current expenses	35700	36600	37500	40200	40650
Depreciation	16000	16000	16000	16000	16000
Residual value of equipment (at the end of the year)	64000	48000	32000	16000	0
Taxable income	15980	15560	20100	18520	19750
Income tax	2876,4	2800,8	3618	3333,6	3555
Net income	13103,6	12759,2	16482	15186,4	16195
Special account funds (total)	714	732	750	804	813
Special account funds of technopark participants	357	366	375	402	406,5
Special account funds of the governing body of the technopark	357	366	375	402	406,5
Net cash inflows	29817,6	29491,2	33232	31990,4	33008

When determining net discounted income and net present value, the technopark management proceeds from a 15% rate on an alternative bank deposit. The results of the calculation of these indicators are given in Table 2.

Table 2. Calculation of net present value of the innovation project, thousand UAH

Indicators	Years					
	0	*1*	*2*	*3*	*4*	*5*
Net cash inflows	-80000	29817,6	29491,2	33232	31990,4	33008
Discount factor	1	1/1,15	1/1,323	1/1,521	1/1,749	1/2,0114
Net discounted cash inflow	-80000	25928,4	22299,6	21850,6	18290,6	16410,8
Net present value	-80000	-54071,6	-31772,0	-9921,4	8369,2	24780,0

Performing calculations, special attention should be paid to two points: the order of depreciation and the presence of special accounts, which play a significant role in determining net cash inflows. As far as the technopark invests in equipment belonging to the third group of fixed assets, then, as mentioned above, depreciation will be carried out at an increased rate – 20% until the carrying value of zero is reached. Therefore, during the implementation of this innovative project, the annual depreciation will amount to 80/5=16 million UAH. Besides, as a result of the targeted state subsidy on the amount of import duty on

component parts and materials that are not produced in Ukraine, two special accounts will be created: the account of technopark participants and the account of the governing body of the technopark. Following formula (4) the funds on these accounts will also be included in the calculation of net cash inflows, besides depreciation and net income.

Thus, this innovative project is profitable because its net present value is greater than zero: $NPV = 24780,0>0$. Let's find other indicators that are necessary for evaluating the innovative project of the technopark.

The profitability index can be found by formula (7):

$$Ip = (25928,4 + 22299,6 + 21850,6 + 18290,6 + + 16410,8) / 80000 = 1,31$$

Using formula (9) we find that in the interval (27%, 28%) the function f(d) changes the sign:

$$d_1 = 27\% \qquad f(d_1) = 274,5$$

$$d_2 = 28\% \qquad f(d_2) = -1334,8$$

Therefore, the root of the equation exists on this very segment. By formula (10) we find the internal rate of return:

$$IRR = 27 + \frac{274,5}{274,5+1313,8} \cdot (28 - 27) = 27,16\ (\%)$$

In order to calculate the payback period, it should be noted that net present value changes its sign from "–" to "+" between the 3rd and 4th years, therefore, using formula (11) we get:

$$T = 3 + 9921,4 / 18290,6 = 3 + 0,54 = 3,54 \text{ (years)}$$

Let's analyze the obtained results: net present value is positive and amounts to UAH 24780,0. Thus, the innovative project is effective and needs implementation; profitability index is greater than one ($Ip = 1,31 > 1$), what confirms the conclusion about the effectiveness of the project; internal rate of return is 27,16%. It is higher than the alternative bank deposit interest rate (15%). Therefore, the project is effective; the innovative project is long-term, as it will pay off in 3,54 years.

These calculations give grounds to claim that the innovative project of the technopark of the E. O. Paton Electric Welding Institute is effective and can be accepted for implementation.

4 Conclusions

Methods of the evaluation of innovative projects of technoparks are here generalized. All of them are aimed at making the right decisions on the choice of this or that innovative project and calculating the economic effectiveness of its implementation. However, the evaluation methods related to absolute efficiency have one major drawback: the calculation of its components is based on the legislation of Ukraine, which, at present, often changes as to technoparks.

As a result of the scientific research, a methodological approach to the evaluation of the effectiveness of innovative projects has been proposed, which takes into account the specifics of the Ukrainian legislation in the provision of certain privileges for technology parks. A separate element in the proposed calculation formulas is the special accounts of technology parks, their participants, and joint ventures.

The application of the proposed methodological approach to the evaluation of innovative projects of technoparks will accelerate the process of selection of innovative projects and their implementation by technoparks, will facilitate the activation of innovative activities and the formation of sustainable innovation culture of Ukraine, what, in its turn, will contribute to the sustainable development of the state.

The proposed methodological approach is tested in the evaluation of an innovative project on the creation of new technology and equipment for semi-automatic welding. The innovation project is a priority for the implementation by the technopark of the E. O. Paton Electric Welding Institute. It also presupposes the production of new lightweight panels for space and rocket, aeronautical, shipbuilding and other industries. The calculations carried out in this scientific study give grounds to state that the innovative project of the technopark of the E. O. Paton Electric Welding Institute is effective and can be accepted for implementation. This confirms the effectiveness of the use of the methodological approach proposed in the article.

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Innovative financing of creative projects on the Kickstarter platform: Ukrainian and Polish experience

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Abstract. In the era of digital economy, the crowdfunding platforms provide the background to mitigate cross-country differences within project financing. In particular, creative projects are important as a vital driver in maintaining business and social sector competitive. Thereby, research problem lays upon the potential of providing crowdfunding support to overcome the creative project divide in different countries. The paper aims to provide scientific support on creative projects innovative financing in Ukraine and Poland within Kickstarter. The research methodology is based on Kickstarter data (10 years; 83 industries and 898 projects) processed by statistical analysis. The Concentration Ratio (CR) was modified to measure the concentration of efforts, considering the largest creative industries within Kickstarter platform. The results section represents high rates of concentration of efforts for Ukrainian creative projects that commercialize tangible physical goods: Product Design and Gadgets. At the same time, in Poland the main concentration of efforts is in the field of intangible intellectual products: Tabletop Games and Video Games. Thus, digital platform is a reflection of interrelations between intangible and tangible values in economies. The study results can be used within national programs of creative innovative projects financial support. In relation to other countries, more extensive study is required.

1 Introduction

1.1 Research question

In the new global economy, creative projects have become an important part of successful innovative entrepreneurship, coming with new ways to meet both economic, cultural and social challenges. Human development projects influence both the modern business and society, transforming standard of living, working conditions within industries, education, cultural and health systems. The success of a few start-ups that started to take care of factors of creative industries development makes up the need to replace some resources as the companies tend to meet new challenges, enhancing their activity into new markets. However, in many cases, the issue of failed human development projects, including creative ones, is mostly related to insufficient funding [1; 2]. For instance, the annually efforts to meet sustainable development goals (SDGs) are estimated to cost about 4.5 tn. USD, including 2 tn. USD for cultural and creative industries development, that makes more than US federal budget [3]

Thereby, determining the impacts of innovative financial resources and mechanisms is becoming more crucial than ever before for the future of creative industries worldwide. In particular, there is already some evidence on crowdfunding and its influence on creative project development. Due to the practical experience, the crowdfunding mechanism is able to overcome many human development challenges and direct more funds to satisfy the most urgent social, economic, cultural and environmental needs. The particular interest should be paid to particular crowdfunding platforms such as GlobalGiving, Indiegogo and Kickstarter, which raise annually about 34 bn. USD within the global crowdfunding industry [3].

Studies have found positive linkages between human development and creative industries development trends and access to crowdfunding services (e.g. D. C. Brabham [4] and B. Boeuf, J. Darveau, R. Legoux [5] on crowdfunding financing of cultural component; M. G. Colombo, C. Franzoni, C. Rossi-Lamastra on crowdfunding influence on human capital and education [6]; M. Farnel 2015 on crowdfunding role to solve health and cultural challenges [7]), although the quality of crowdfunding services provided has been questioned (e.g. M. Barbi, M. Bigelli [8] and J. H. Ganatra [9]).

In light of recent trends of crowdfunding, it is more difficult to find studies that provide a comparative analysis of crowdfunding effectiveness indicators, considering the relation between crowdfunding financing and successful creative projects implementation in particular countries. Thus, the current study tends to

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highlight the tendencies of creative projects crowdfunding financing, using the data of two neighboring countries, namely Poland and Ukraine. At the analytical part of the research, attention is paid to the creative projects of the above-mentioned countries crowdfunding financing on Kickstarter, which is one of the leading crowdfunding platforms globally. The genesis of this thesis can be traced back to the time the authors became interested in innovative sources of social and economic development financial support in Ukraine and abroad.

1.2 Previous researches

Several previous studies and international organizations reports have found that crowdfunding has a significant potential to support creative industries worldwide by boosting innovation in the creative sector, generating wealth and social growth [4-10].

More recently, literature has emerged that offers findings of the relationship between the trends of financing and creative industries development at the national or cross-country level, largely with a focus on the health and educational components. In particular, some researchers have found an association between education and health sectors financing and improvements in both access to these services and related creative industries development outcomes [13, 14], considering the possibility and potential effect of innovative financing across national economies. Other studies pay attention to different social and economic sectors financing [11, 12], considering the possibility to achieve both social and economic progress.

Particularly, in the literature on innovative sources of creative project financing, the relative importance of crowdfunding essence has been subject to considerable discussion. Even though crowd co-financing relates to the previous centuries, it is defined as an innovative paradigm within the scientific concept nowadays.

According to G. Le Bon, “While all our ancient beliefs are tottering and disappearing, while the old pillars of society are giving way one by one, the power of the crowd is the only force that nothing menaces, and of which the prestige is continually on the increase. The age we are about to enter will in truth be the era of crowds” [15]. Since the late 1990s collective efforts of individuals who network and pool their resources, usually via the Internet, to support the efforts initiated by other people or organizations are defined as crowdfunding [16; 17].

For instance, Hengchen, and Zhang are paying attention to the reward-based crowdfunding concept, when crowdfunding aims to increase the capital volume from potential consumers to reach a measure of social and economic goals [18]. Kindler, Golosovsky, and Sorin define crowdfunding among the emerging channels for spreading social collective action and funding of novelty in all these domains, considering the potential of various crowdfunding platforms. In particular, these experts pay attention to the lack of experience on Kickstarter, Indiegogo and Sellaband mechanism of data collection [19]. Dahlhausen et all continue researches about the crowdfunding potential to support creative projects that are funded by the masses through websites such as Kickstarter and Indiegogo. Thereby, these crowdfunding platforms are becoming popular both within theoretical researches and practice that has been steadily gaining attention in the last few years, across many different sectors of society [20].

In particular, nearly 5 bn USD are collected from nearly 5 mln. backers on Kickstarter yearly, which are divided within about 200 thousand successful funded projects [3]. In light of recent trends of digital society growth and increase the number of funding projects that have reached their goals, Kickstarter becomes an important source for creative industries financing globally. Also, following the Web of Science Core Collection report, the total publication volume on Kickstarter topic is increasing since 2000. In particular, the highest increase has taken place within the last 5 years. Thus, the chosen problem is of a significant scientific interest nowadays.

1.3 The scientific problem

The scientific problem of this article lays upon the potential of providing flexible crowdfunding support to overcome the social and economic divide in order to improve the creative sector environment in Ukraine and Poland. The hypothesis of the paper has both theoretical and applied background, concerning the crowdfunding impact on human development process and innovative sources of financial support, which aims to activate innovative creative projects implementation. *The aim* of the current study is to identify similarities and differences, discover the best practices and present how the modern innovative creative projects are crowdfunded in Ukraine and Poland, based on Kickstarter statistic. The *object* of the research is crowdfunding boost within two neighboring countries. The *subject* is creative projects development financing volumes on Kickstarter, contributing the social and economic growth within both countries.

1.4 The research methodology

The *research methodology* is based on Kickstarter data processed by statistical analysis. Data on crowdfunding in various types of projects were collected by authors directly from Kickstarter. A time period of research is 10 years: 2009 – 2019; the number of industries: 83; the number of projects: 898. Total funds raised by researched Polish projects are 24 993 092 $; by Ukrainian projects are 5 046 334 $. During the analysis, the following data were studied: Industry, stated goal ($), Raised funds ($), Reaching the goal (%), Total funds raised ($), Max. successful project ($).

A higher concentration of efforts allows players to maximize the likely financial result while expanding efforts is designed to reduce the risks of failure. For measuring concentration of efforts, the Concentration Ratio (CR), proposed by Bain to analyze the market

share, was used [21]. *The scientific novelty of the methodology is as follows:* in the study, the Concentration Ratio (CR) is applied with the following modifications: 1) not the share of the largest firms in industry revenue, but the share of the largest industries in the general market; 2) not a market for products, but a market for resources (namely, crowdfunding financing). The Three-Branch Concentration Ratio / The Ten-Branch Concentration Ratio measures the total market share of the three / ten largest industries on the Kickstarter platform accordingly.

1.5 The current research structure

The current research consists of the following parts:
- primarily, a theoretical framework based on innovative sources of creative projects financing and crowdfunding definition is provided;
- secondly, the Kickstarter phenomenon is described; the placement of Ukrainian and Polish creative projects on a crowdfunding platform is analyzed; the authorial approach of efforts concentration for crowdfunding financing is represented (Ukrainian and Polish Kickstarter experience);
- then, the research conclusions on crowdfunding effectiveness for creative industries development in Ukraine and Poland are provided.

The research practical implication is that results can be used within national innovative financial support strategies to accept community challenges both on national and regional levels.

2 Main theoretical assumptions of the research

2.1 Innovative sources for creative projects financing

In the context of the current activity of economic entities, there is an interaction between the traditional components of the chain of production resources, namely "human resources – material resources – financial resources". However, the goals and objectives of economic and cultural development, the strategic importance of each component is changing, depending on the environment [22, p. 139]. The primary requirement for innovative activity within social, economic and creative sectors means qualitative changes of human and financial resources.

Thereby, the improvement of the qualitative characteristics of human resources creates the basis for scientific, cultural and technical development, innovative social and economic initiatives creation, innovative projects implementation and innovative characteristics of creative industries development within the national economy. At the same time, sufficient and systematic funding is needed to expand the range of human and material resources. Following the above-mentioned information, fundraising allows to systematize the process of financial resources attraction and diversify the sources of their attraction.

Despite traditional resources of creative projects, financing that involves attracting the resources of economic entities, state budget resources and foreign investors; fundraising involves the use of both "real" and "virtual" resources. Thus, resources and opportunities of national economic entities, financial institutions, the state, and foreign investors are expanded due to the digital technologies widespread (Figure 1).

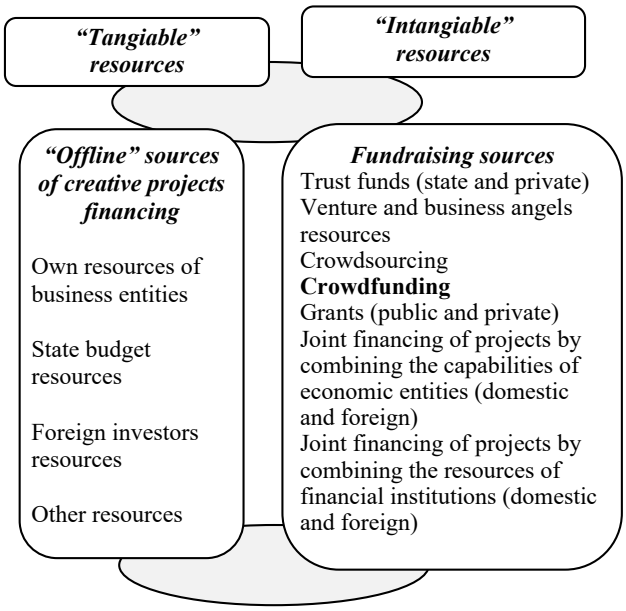

Fig. 1. Fundraising and opportunities for creative projects financing

Direct mailing, crowdsourcing (obtaining the necessary services through the fulfillment of socially important tasks by a multitude of volunteers coordinating activities through information technology) and **crowdfunding** (the process of voluntarily cooperation of entities who provide financial or other kind of assistance to solve particular social challenges through Internet), virtual negotiations are considered in the context of online and email fundraising [23, p. 279].

This proves the potential for attracting alternative private resources to achieve the goals of sustainable human development and creative industries growth.

2.2 Theoretical framework of crowdfunding

In the context of substantiating the potential of innovative financial mechanisms to ensure creative project implementation in Ukraine and Poland, the attention should be paid to the widespread of Internet technologies to all areas of human life, including cultural ones. In particular, the rapid development of information technology is transforming how people use, shape, and disseminate educational and cultural content, their ideas, participating in social life.

International organizations tend to pay attention to the measure of key indicators of competitiveness of the national economy, including the potential to create

innovation and improve living standards, taking into account the level of scientific and technological development, infrastructure and financial market trends [24]. This is associated with the rapid development of the Internet environment, which forms the so-named "online" infrastructure. Transition to the information society causes structural changes in an aggregate capital to provide social benefits. The volumes of "intangible" financial resources are rapidly growing. Thus, fundraising online sources are becoming globally widespread.

In particular, the crowd technologies concept has received considerable critical attention within the modern socially-oriented society. The term "crowd", which means common efforts to provide financial support for creative projects, is at the heart of our understanding of crowd technologies. The mentioned technologies are representing a mechanism of a wide range of stakeholders' online cooperation to meet urgent social and economic challenges [25, p. 426].

Thereby, the crowd technologies represent a major area of interest within the field of innovative social and economic changes financing. At the same time, there is a wide range of crowd technologies diversity within the international practice of creative projects financial support (Figure 2).

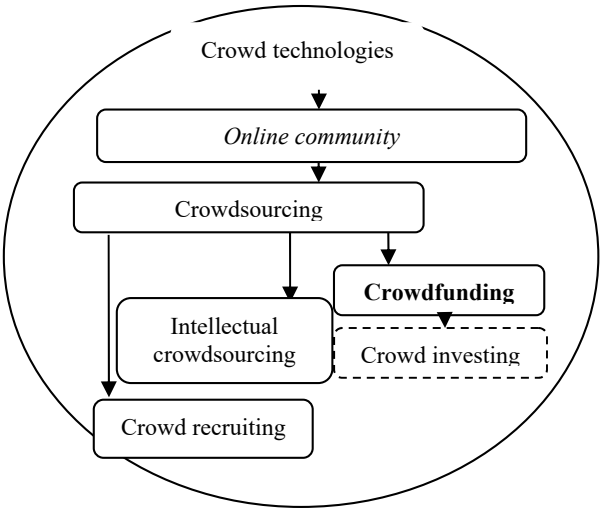

Fig. 2. Crowd technologies spectrum

Crowd technologies can play an important role in addressing the issue of a virtual community. Reingold defines the virtual community as a social-oriented network that involves the support of a large group of people in open discussion to achieve specific goals [27]. To commercialize virtual community capabilities, it is advisable to use crowdsourcing capabilities, which characterize opportunities to attract the necessary resources through the Internet. For instance, Eric von Hippel examined the impact of crowdsourcing into a user-friendly innovation. Thus, the crowd technology development depends on the growing demand for social investment within modern society.

In particular, intellectual crowdsourcing technologies involve the intellectual collaboration of particular individual knowledge and skills through social networks.

Such common interaction aims to create an intellectual product, integrating the knowledge and skills of a significant number of people ("crowd"). At the same time, intellectual interconnections have no territorial, corporate, professional, social and cultural barriers due to their online widespread [28; 29]. However, the theoretical and applied evidence shows the possibility to attract additional human resources through the Internet (crowd recruiting technologies).

At the same time, modern studies have provided evidence on the growing influence of sustainable financing into creative project implementation through the crowdfunding mechanism. The theoretical considerations provide the concept of crowdfunding that is defined as a combination of the terms crowd and funding. However, the crowdfunding process has mostly practical applications. Thereby, the crowdfunding influence on creative project development should be evaluated as the result of specific crowdfunding projects implementation. The essence of crowdfunding may be defined as "worldwide financing", "a social bank", "a collective wallet", "public financing", "common fold". The current study aims to test the creative projects' successful implementation through an innovative mechanism of crowdfunding platform functionality.

3 Research results

3.1 Global crowdfunding market trends

Crowdfunding platforms are considered as major drivers for social and economic development worldwide. By Statista data, total transaction value in the crowdfunding segment amounts to $ 6,923.6 mln in 2019 (Figure 3).

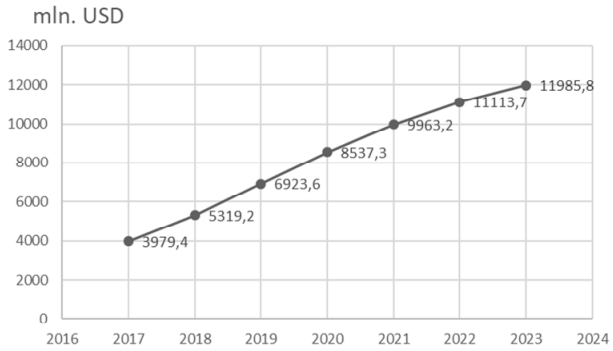

Fig. 3. Global crowdfunding trends (based on Statista [30])

Another important practical implication is that the top crowdfunding platforms play an important role within social and economic development within particular economies. Thereby, this particular research finding points to the need for the leading crowdfunding platforms functionality analysis (Table 2).

Under Statista data, the quantity of crowdfunding campaigns tends to be about 8724 thousand in 2019. At the same time, the number of funding campaigns in the crowdfunding segment is expected to amount to 12,063.9 thousand by 2023 [30] (Figure 4).

Table 2. Top 10 crowdfunding platforms worldwide.

Crowd-funding plat-form	Main characteristics	Core areas of financing
Kickstarter	The crowdfunding platform is known as one of the most popular worldwide. The initiative has raised over $4.5 billion with more than 170 000 projects funded since its inception in 2009. Categories include Arts, Comics & Illustration, Design & Tech, Film, Food & Craft, Games, Music, and Publishing. Kickstarter is an all or nothing platform, which means that you don't get your funds unless you complete your campaign. Kickstarter mainly provides financing to assist within social, high- technology and creative business development	Tech and creative entrepreneurs, venture business, social business, inventions
Indiegogo	The crowdfunding platform aims to provide assistance within the process of non-profit business activity. The crowdfunding platform works similarly to Kickstarter, except it doesn't have an exclusively all or nothing fundraising model.	Social initiatives
Patreon	Patreon is a monthly subscription platform where supporters and donors provide regular monthly contributions, rather than one bulk payment.	Creative venture or artist
GoFundMe	The crowdfunding site collects a 2.9% processing fee and 30 cents for every donation.	Short-term personal projects
Crowdrise	Crowdrise is geared more toward helping "real-world issues", rather than funding for-profit ventures.	Cycling and walking events, nonprofit event fundraising, and online social fundraising
PledgeMusic	You can provide rewards for donors who pledge a certain level, such as downloadable digital music.	Music and musicians development
MightyCause	Financial support for special events for children and family, education, animals and pets, and even faith-based causes.	"Worthy causes"
InKind	The financial assistance is provided to support restaurant business representatives	Restaurant business
Crowdfunder	The platform pay angel investor or venture capitalist attention to particular projects	Venture, innovative initiatives
Give	This is a WordPress plugin to add to your WordPress blog and use it to collect donations from visitors.	Online donation

Some crowdfunding platforms are more geared to developing products, others are about funding artistic endeavors, and still, others are ideally suited to nonprofits. The particular sites will collect all the money as it comes in; others will not collect it until the goal amount is reached.

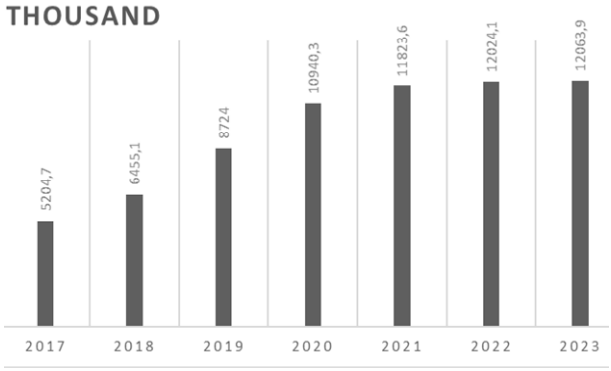

Fig. 4. Global crowdfunding campaigns (based on Statista [30]).

3.2 Kickstarter: grandness of the phenomenon

The Kickstarter platform was launched on April 28, 2009. However, its history goes back to 1713, when Alexander Pope set out to translate 15,693 lines of ancient Greek poetry into English. In exchange for a shout-out in the acknowledgments, an early edition of the book, and the delight of assistance within bringing a creative work into the world, 750 subscribers pledged two gold guineas to support the author's effort before he put pen to paper.

In 2015, Kickstarter was reincorporated and achieved the status of a Benefit Corporation. Even though Benefit Corporations are for-profit companies, Kickstarter is considering the impact of funded decisions on society, not only shareholders. Radically, a positive impact on society becomes part of a Benefit Corporation's legally defined goals. The crowdfunding platform has its unique mission, vision, and goals, which also makes the basis for Kickstarter stockholders' activity (Table 2).

17 million people have backed a project, $4.7 billion has been pledged, and 174 634 projects have been successfully funded. However, Kickstarter statistic is changing daily (Figure 5).

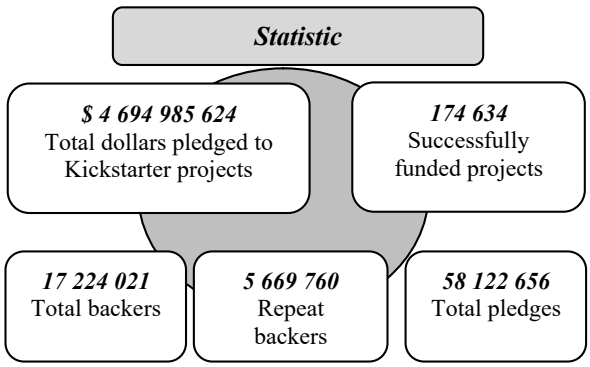

Fig. 5. Kickstarter statistic as of December 12, 2019.

Statistics are available for the site overall as well as each of the 15 project categories. Because the

Kickstarter platform is represented as a Benefit Corporation, both creative and high-technology projects are financed on the platform (Table 3).

Table 2. Kickstarter platform phenomenon (based on Kickstarter statistics [31]).

Kickstarter parameters	Overview
Kickstarter mission	The mission is to help bring creative projects to life.
Kickstarter goals	1. Kickstarter will create tools and resources that help people bring their creative projects to life, and that connect people around creative projects and the creative process. 2. Kickstarter will care for the health of its ecosystem and integrity of its systems. 3. Kickstarter will engage beyond its walls with the greater issues and conversations affecting artists and creators.
Kickstarter vision	The vision is for-profit companies support, which activity aims to provide both economic and social impact
Community	Kickstarter is an enormous global community built around creativity and creative projects. Over 10 million people, from every continent on earth, have backed a Kickstarter project.
The main stakeholders groups	Artists, musicians, filmmakers, designers, and other creators
Kickstarter team	Independent, founder-controlled company of 153 people working together in an old pencil factory in New York City.
Kickstarter operations to support sustainability	Kickstarter will seek to limit environmental impact. It will invest in green infrastructure, support green commuting methods, and factor environmental impact when choosing vendors. Additionally, Kickstarter will provide recommendations and resources that help creators make environmentally conscious decisions on tasks, like shipping and packaging, that are common to the use of its services.
Financial model	If a project is successfully funded, Kickstarter applies a 5% fee to the funds collected. All pledges are processed securely by our third-party payments partner, Stripe. These payment processing fees work out to roughly 3-5%. If the project does not reach its funding goal, there are no fees.

However, the creative component of human development needs to expand a range of financial resources for their support due to the rather high risk of such kind of social investment. At the same time, the creative projects are the most successful on the Kickstarter platform (Table 4).

Thus, Kickstarter is a funding platform for creative projects – everything from films, games, and music to art, design, and technology. The available statistics and analytical researches show that in general Kickstarter projects tend to be successful (about 50 %) rather than fail (about 35 %) or get cancelled (about 8%). Given the data provided on the official website, there is a difference among the Kickstarter project outcomes in particular areas. For instance, the highest successful implication is typical for projects in music (82%), theatre (63%), film and video (63%). At the same time, nutrition, games and publishing have the lowest success rates (less than 50 % for each group). Thereby, the Kickstarter database analysis confirms its role as the creative projects specialized platform.

Table 3. Kickstarter platform projects and financial support volumes.

Project category	Launched	Total $	Successful $	Live $	Live	Success, %
All	478,806	4.82 B	4.32 B	41 M	3,866	37.57
Games	50,909	1.21 B	1.12 B	14.25 M	659	40.39
Design	40,361	1.09 B	990.20 M	12.74 M	382	38.08
Technology	41,805	905.46M	794.19 M	6.33 M	403	20.64
Film & Video	74,130	464.72M	395.23 M	1.35 M	418	37.61
Music	61,956	246.00M	224.81 M	941.85 K	290	50.00
Fashion	31,100	184.16 M	161.50 M	832.13 K	252	27.91
Publishing	49,261	176.84M	155.33 M	967.09K	353	33.02
Food	29,729	160.53M	135.62 M	670.60K	209	25.19
Art	38,130	126.72M	112.95 M	1.04 M	430	44.02
Comics	15,686	107.76M	100.08 M	1.28 M	214	58.69
Photography	12,307	48.06M	42.19 M	129.52 K	58	32.21
Theater	12,229	46.69M	41.91 M	61,597	45	60.09
Crafts	11,262	19.57M	16.12 M	86.54 K	97	25.04
Journalism	5,690	17.72M	15.43 M	73,283	37	22.71
Dance	4,251	14.77M	13.71 M	40,838	19	61.84

Table 4. Successful projects on the Kickstarter platform, projects.

Category	< $1000	$1000-9999	$10000-19999	$20000-99000	+$100K	+$1M
All	23,189	96,770	25,679	25,993	6,397	426
Music	3,061	21,634	4,217	1,825	92	2
Film & Video	3,252	15,553	4,362	4,117	429	7
Games	1,649	8,399	3,557	4,829	1,698	163
Art	4,551	9,655	1,411	890	84	5
Publishing	2,345	9,964	2,181	1,537	124	0
Design	1,061	4,994	2,641	4,643	1,774	112
Comics	1,255	5,731	1,015	953	125	1
Fashion	1,561	3,870	1,433	1,474	265	6
Technology	498	2,304	1,229	2,775	1,620	121
Food	737	3,045	1,765	1,779	102	9
Theater	1,043	5,312	644	303	19	0
Photography	735	2,142	588	443	37	0
Crafts	956	1,447	221	160	12	0
Dance	239	2,046	253	78	1	0
Journalism	246	674	162	187	15	0

3.3 Ukraine and Poland on the Kickstarter platform

Ukraine and Poland are among the leaders in Eastern Europe on the Kickstarter platform. In particular, following the statistic on the number of projects, both countries are the leading ones (Figure 6).

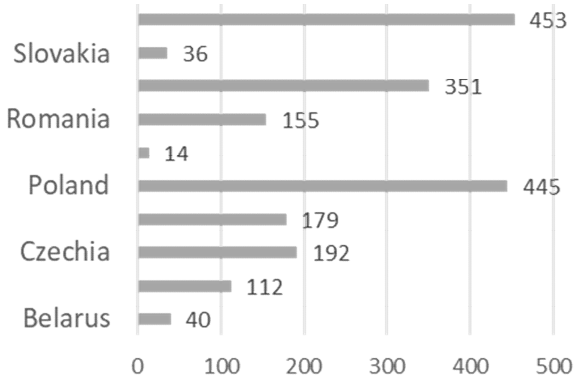

Fig. 6. The comparative analysis of projects number on Kickstarter, projects.

The same tendencies are defined for the average volumes of investment per one backer in these countries (Figure 7).

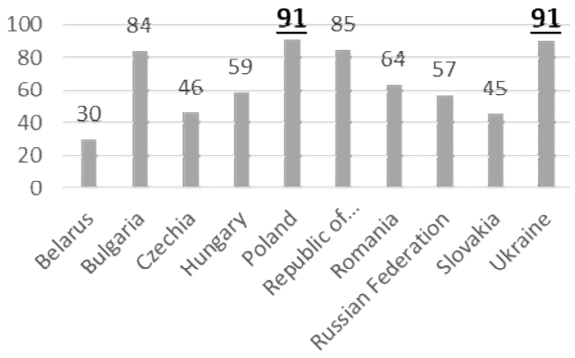

Fig. 7. The comparative analysis of the average volumes of investment per one backer on Kickstarter, USD.

Thus, Ukrainian and Polish creative projects gather the main part of total funding (Figure 8).

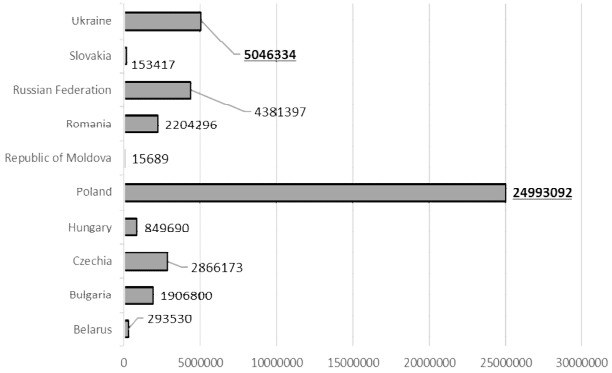

Fig. 8. The comparative analysis of total funds raised on Kickstarter, USD.

At the same time, an important indicator of crowdfunding financing effectiveness in a particular country is the share of successfully funded projects. The following data have been collected to analyze the above- and below-mention indicators of Ukrainian and Polish creative projects Kickstarter funding, including timeframe of ten years (2009 – 2019); total number of industries: 83; total number of projects and project essence: 898; stated goal and raised funds in USD; the share of reaching goals; number of backers; project campaign start/end/duration; project status; total funds raised in USD; successful projects share and funding volume (Figure 9).

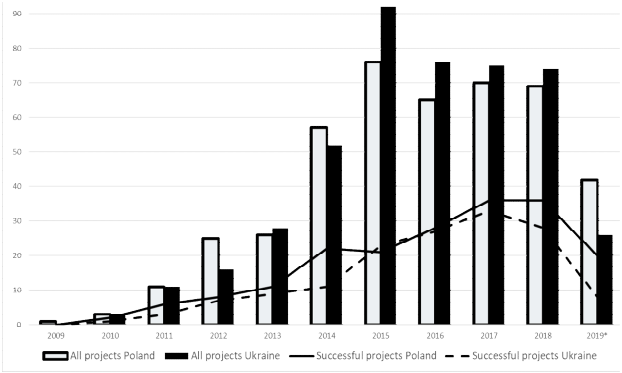

Fig. 9. The successful Ukrainian and Polish creative projects share and trends on Kickstarter platform, % (black for Ukraine; white for Poland).

Ukraine is slightly overtaking Poland by the number of announced projects, but Polish projects are more successful and more often reach established investment goals (Figure 10).

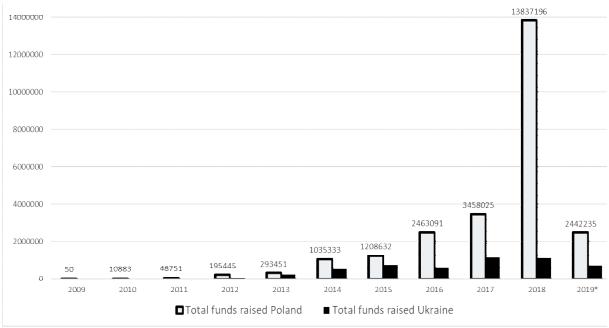

Fig. 10. Ukrainian and Polish creative project financing trends on Kickstarter, projects (black for Ukraine; white for Poland).

Thereby, both countries are the leaders on the Kickstarter platform. However, Polish creative projects seem to be more effective due to the different levels of effort for crowdfunding financing concentration.

3.4 Creative projects in Ukraine and Poland: concentration of efforts for crowdfunding financing (Kickstarter experience)

Ukrainian and Polish creative projects are among leaders on the Kickstarter platform following both qualities' and quantities' indicators. However, there is a different approach, concerning countries profile industrial structures (Figure 11).

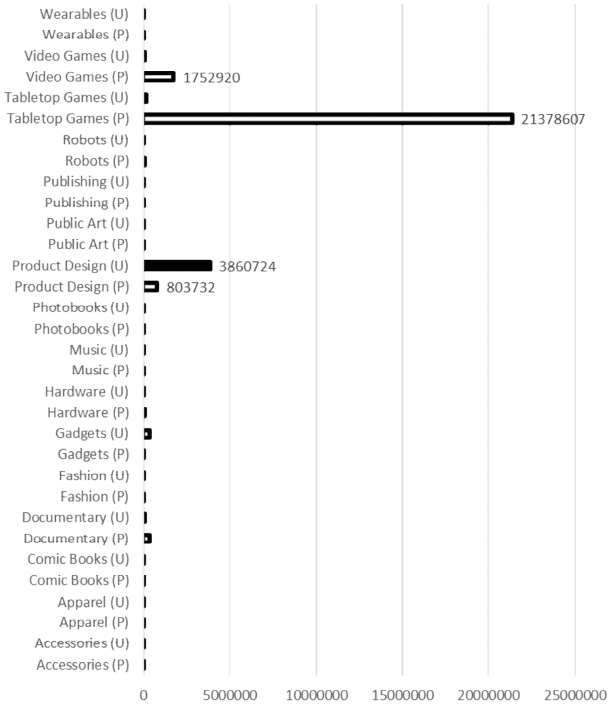

Fig. 11. Country profiles: industries, projects (black for Ukraine; white for Poland).

The country Kickstarter profile of Poland is defined as *a concentration of intangible intellectual products* (Table 5).

Table 5. Industries: concentration of efforts in Poland.

	Industry	All projects	Successful projects	Total funds raised
1	Tabletop Games	122	83	21 378 607
2	Video Games	61	31	1 752 920
3	Product Design	17	6	803 732
4	Documentary	38	13	362 596
5	Robots	2	1	76 372
6	Hardware	4	1	67 551
7	Wearables	2	2	58 096
8	Music	5	3	41 904
9	Comic Books	2	2	38 109
10	Public Art	4	1	33 442

At the same time, the country Kickstarter profile of Ukraine is defined as *a concentration of tangible physical goods* (Table 6).

The chosen dataset provides the information on success rate of Ukrainian and Polish creative project on Kickstarter. In particular, in 2019 more than 30 % of Ukrainian and more than 40 % of Polish creative projects were successful. An average percent of project goal achievement is about 150 % and 220 % accordingly. The above-mentioned tendencies are reflected within the most successful Ukrainian and Polish creative projects on the Kickstarter platform (Figure 12).

A successful Kickstarter crowdfunding campaign duration varies from 7 to 90 days in Ukraine and from 14 to 90 days in Poland. The number of people who supported the creative project on Kickstarter varies from 2 to 6 110 person in Ukraine and from 5 to 41 939 person in Poland.

Table 6. Industries: concentration of efforts in Ukraine.

	Industry	All projects	Successful projects	Total funds raised
1	Product Design	141	71	3 860 724
2	Gadgets	12	7	359 461
3	Tabletop Games	13	5	186 856
4	Documentary	30	5	84 755
5	Video Games	19	3	58 254
6	Accessories	13	5	39 475
7	Photobooks	4	1	36 393
8	Apparel	8	2	32 094
9	Publishing	6	2	31 866
10	Fashion	10	4	27 466

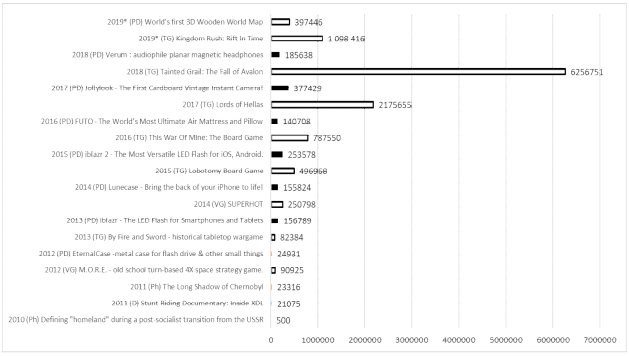

Fig. 12. The most successful Kickstarter projects: Ukraine vs Poland, USD (black for Ukraine; white for Poland).

The smallest successful Ukrainian Kickstarter project is “Learn English with 850 Basic English words”. Two person donated 50 USD during 7 days to achieve the project goal, namely to shoot a short movie in English, using dictionary words Basic English 850. The creator already had the necessary equipment, a small studio, and students who wanted to play in film. Thereby, the crowdfunding campaign played rather the role of advertisement, motivation for Ukrainian people to learn English.

The Ukrainian creative project on Kickstarter that attracted the widest audience was “Jollylook – The First Cardboard Vintage Instant Camera!”. 6 110 person donated 377 429 USD instead of 15 000 USD during 31 days (in April 2017) to produce a simple fold out camera for analog snapshots, made entirely from recycled paper and cardboard. As the result of crowdfunding campaign on Kickstarter, about 1043 cameras were sold on online pre-order for 46.958 USD as of November 2018. In December 2019, the Camera is represented at Amazon with 4 ranking. There are more than 160 posts from all over the world on Camera features only on Instagram. There are also many product video reviews on YouTube and Facebook with positive assessment of Camera design and images quality.

The longest Ukrainian crowdfunding campaign duration was 90 days to raise funding for “The Long Shadow of Chernobyl” project. The project goal was to raise awareness of the Chernobyl Nuclear Disaster 25

years later through a retrospective photo book by Gerd Ludwig. The Kickstarter campaign was rather successful. The project initiator gathered twice more funding from 435 donors. Gerd Ludwig spent about 5 weeks in Chernobyl region, photographing deep inside the reactor. One year later, the images were first exhibited at the EBRD headquarters in London, helping to raise the addition 1.5 billion dollars needed to build the New Safe Confinement and safely deconstruct the ailing Chernobyl shelter. The project is still active nowadays. The photo book is represented on Amazon.

The shortest Polish crowdfunding campaign lasted during 11 days to assist Violet & Myo within their Eastern Europe tour, namely to cover their train fare. As the result, Violet & Myo achieved their goal.

The most successful Polish crowdfunding campaign lasted 23 days and enabled to gather 6 199 036 USD out of desirable 50 194 USD (41 939 backers) for “Tainted Grail: The Fall of Avalon” project. This adventure, survival cooperation Board Game set in unique grim world inspired by Arthurian Legends. Currently, the game ranking is 8.8 out of 10 (nearly 1 K comments).

The longest Kickstarter Polish crowdfunding campaigns lasted 90 days (a screenplay “Mike & Zack's Righteous Journey” and a journalist research “Life In the Shadow of Auschwitz”). The projects were successfully funded for more than 100 %.

Despite available theoretical researches on crowdfunding functionality, there is no approved methodology to estimate the concentration of efforts for crowdfunding financing. Thereby, to examine this issue the concentration ratio (CR3 and CR10) methodology was applied within the current research (Table 7). The table shows that the concentration ratio, based on the three and ten leading branches, indicated a higher level of effort polish projects' concentration on the Kickstarter platform.

Table 7. The concentration of efforts indicators for Ukraine and Poland.

Poland	All projects 445	Successful projects 190	Total funds 24 993 092
Concentration of efforts indicators			
CR3-Index	44.94	63.16	95.77
CR10-Index	57.75	75.26	98.48
Ukraine	All projects 453	Successful projects 150	Total funds 5 046 334
Concentration of efforts indicators			
CR3-Index	36.64	55.33	87.33
CR10-Index	56.51	70.00	92.94

Thus, despite the equal quantity and volumes of crowdfunding financing in Poland and Ukraine, Polish fundraisers pay more attention to intangible intellectual products. This causes the highest concentration of efforts, developing creative projects in Poland.

4 Conclusions

Given all that has been mentioned so far, one may state that crowdfunding financing is getting growing effectiveness within creative project implementation. The primary analytical research of Kickstarter statistics shows the increasing trends of total funds raised and all projects financed both in Ukraine and Poland.

At the same time, the study results show that the global digital platform (Kickstarter for creative industries) is a reflection a reflection of interrelations between intangible and tangible values in economies. Ukraine and Poland were chosen for comparison because of their common geographic location, close and growing economic cooperation. At the same time, the Polish GDP per capita exceeds the corresponding Ukrainian indicator more than tenfold. However, Polish creative project financing trends on Kickstarter are more successful than Ukrainian ones.

For measuring the concentration of efforts for comparing countries, the Concentration Ratio (CR), proposed by Bain to analyse the market share, was successfully applied with the following modifications: 1) not the share of the largest firms in industry revenue, but the share of the largest industries in the general market; 2) not a market for products, but a market for resources (namely, crowdfunding financing). The proposed “Three-Branch Concentration Ratio” and “The Ten-Branch Concentration Ratio” measure the total market share of the three / ten largest industries on the Kickstarter platform accordingly.

The results of the study revealed high rates of concentration of efforts of Ukrainian projects in creative industries that commercialize tangible physical goods: Product Design (141 projects) and Gadgets (12 projects). At the same time, the main concentration of efforts of Polish creative projects is observed in the field of intangible intellectual products: Tabletop Games (122 projects) and Video Games (61 projects).

The same trend is confirmed by the industry affiliation of the most successful projects: 1) the most successful Ukrainian project is “World’s first 3D Wooden World Map” (Industry: Product Design); 2) the most successful Polish project is “The Fall of Avalon” (Industry: Tabletop Games).

There is an urgent need to concentrate more efforts on the crowdfunding process in Ukraine. Thereby, the study results of the can be used by the Ministry of Economy of Ukraine that provides organizational and financial support for creative innovative projects in part of crowdfunding platform access stimulation.

In particular, the Ukrainian crowdfunding stakeholders tend to pay attention on the following activities:

- stimulating the development of crowdfunding research in the works of Ukrainian scientists;
- creation of a centralized system of informing the national business entities and investors regarding the possibility of online cooperation;
- intensification of cooperation between public and private backers, who are ready to finance creative projects.

The essence of crowdfunding is both applied and theoretical question. Thus, the potential crowdfunding stakeholders pay attention to the factors of successful crowdfunding campaign, including:

- ability to gather a network of enthusiastic stakeholders, who will assist at the initial stage of crowdfunding campaign;
- provide an effective system for stakeholders' stimulation;
- provide a serious business plan and project clear explanation for future stakeholders;
- demonstrate your previous achievements and professional skills;
- provide an effective video pitch, keep it short and concise;
- study of online audience needs.

Despite there is already a measure of researches on crowdfunding results and functions, experts still have a lack of information on some applied aspects, including:
- a measure of long-term results from crowdfunding financing;
- lack of information on successful crowdfunding campaign principles;
- lack of crowdfunding statistic both on global and national levels.

Thereby, there is a need for further crowdfunding research, considering its practical implication within modern society. In particular, in relation to other countries, these studies should be applied with caution due to the national economies' peculiarities. More extensive study is required. Thereby, this is the subject for future researches.

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Method of investment projects evaluation for territorial communities taking into account the concept of sustainable development

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Abstract. The article is devoted to solving the problem of evaluation and selection of investment projects aimed at developing territorial communities, taking into account the concept of sustainable development. The problem of choosing from possible alternative solutions is not easy for decision makers and requires qualified justification. This is especially important in the context of decentralization reform, advancement of Ukraine towards society openness, increase of transparency requirements to the authorities and their results. Decision making on the basis of the sustainable development concept determines the evaluation of investment projects in terms of their effectiveness in solving problems of social, economic and environmental nature, finding a balance between these components. The peculiarity of the assessments is not so much quantitative as qualitative character, which makes it expedient to use the apparatus of fuzzy logic. The fuzzy model of evaluation of investment project aimed at developing a territorial community is constructed and substantiated in the work. The model is based on quantitative and qualitative evaluations of the social, economic and environmental components of the concept and enables a "soft" – qualitative evaluation of the investment project under consideration. Modeling results are based on the method of deciding on the choice of investment projects for the development of territorial communities. The proposed model and method are implemented by the Fuzzy Logic Toolbox application, were applied to substantiate decisions for the territorial community of Zaporizhzhia region, and can be used in the development of decision support systems to quantify the decisions and variant calculations.

1 Introduction

The challenges of the 21st century make it necessary to ensure economic growth in the country on a balance basis. This implies the inheritance by descendants of all environmental components in a condition no worse than exists today. This is the concept of sustainable development, which was first emphasized in 1987 in the report "Our Common Future" by the International Commission on Environment and Development [1].

This concept provides an opportunity to provide comprehensive management of territorial socio-economic systems, integrates the agreed aspects of economic, environmental and social development of society, creates conditions under which from one generation to the next the quality and safety of human life will not diminish, the environment will not deteriorate and socio-economic progress will be ensured [2].

Ensuring balanced development of the regions is one of the priority directions of Ukraine's regional policy at the present stage of its transformational changes. Achieving this priority is facilitated by decentralization reform, which aims at the enhancing self-development of territorial socio-economic systems, their self-regulation, self-improvement with efficient use of available internal and external resources to meet the needs of residents [3, 4].

The task of decentralization reform is to create the conditions for local issues to be addressed independently. Thus, in the light of global trends, the newly formed United Territorial Communities (UTCs) face the need to create a system of governance that would provide prospects for the development of the territory not only from the point of view of socio-economic efficiency, but also by adhering to the principles of sustainable development oriented on interest of future generations. The Sustainable Development Goals, which were endorsed in 2015 at the United Nations Summit [5], are the baseline that sets out the forward-looking trends of the world, Ukraine and, in particular, the UTCs.

Each territorial community is tasked with identifying areas and means that will enable sustainable development, both in the long term and at every step of government.

Thus, the issue of raising capital for the environmentally-oriented development of both the economy of Ukraine and individual communities is currently acute. Ukrainian experts [6] point out that the

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implementation of European integration reforms in the environmental sector of Ukraine requires the introduction of a "green" economy and development of territorial communities, ensuring human rights for a clean environment, decent work. The level and quality of the population life, as well as the development of human capital, depend on the social aspects of investment. But today, UTCs do not always understand and take into account the importance of social aspects of investing.

The problem of choosing from possible alternative solutions is usually not easy for decision makers and requires qualified justification. This is especially important in the context of Ukraine's move towards openness of society, increasing demands for transparency of government actions and their results.

The scientific works of both domestic and foreign scientists [7-11] are devoted to the study of socio-ecological and economic development of the region, in particular those related to the development of models for assessing its level. The studies that focus on the quality of investment projects at regional level [12-15] take into account only certain aspects (environmental, social or economic). The paper [16] proposes a multi-criteria approach to the selection of investment projects. However, the development of regional systems for the united territorial communities, particularly that comprehensively take into account the requirements of sustainable development is missing.

In these circumstances, it is extremely important to develop and apply models and methods of quantitative and qualitative substantiation of the decisions made by the united territorial communities and aimed at solving problems of social, economic and environmental character in order to improve their own well-being and quality of life.

The purpose of this work is to develop and validate a fuzzy model for evaluating the quality of investment projects for territorial communities, taking into account the concept of sustainable development and recommendations for its application in the process of strategic decision-making for the community.

2 Materials and methods

The essence of the problem, which is devoted to this work, lies in the evaluation and comparative analysis of investment projects. These projects are presented to the local community leadership (UTC) for choice and will depend on its further development in the context of implementing a sustainable development strategy.

Sustainable development of territories is ensured by a combination of environmental, economic and social components (spheres), each of which can be assessed by a whole set of relevant indicators.

For further modeling of the development level for UTC as a result of realization of the investment project for each component one measurable indicator is selected, which in the further researches can be replaced by, for example, an integral indicator for a certain sphere. Each of these marks (indicators) characterizes the effectiveness of an investment project for an UTC in terms of a specific area.

It should be noted that the choice of a measured indicator faces the problem of choosing a measurement scale and methods of its measurement / calculation. If a quantitative indicator can be chosen to evaluate the level of economic development, for example, the rate of increase / decrease in community budget revenues resulting from the project implementation, and to evaluation the social impact can be use the number of jobs that will be created during the project implementation, then the environmental component is not always suitable for formal quantitative measurement procedure. Therefore, often only expert evaluation can be used to measure it. However, confidence in such evaluations may be different. Thus, the rating system, which characterizes the effectiveness of the investment project implementation, can contain both quantitative and qualitative indicators.

With this in mind, we come to the conclusion that in order to solve the problem of evaluating investment projects in the context of the concept of sustainable development and to make management decisions on the development of an UTC, it is advisable to use data mining tools, namely fuzzy modeling.

Its founders – L. Zade [17], D. Dubois, A. Prad, A. Kofman devoted their research to problems of the use of a fuzzy logic for the analysis of economic systems. The works of A. Matviychuk [18], A. Nedosekin, S. Orlovsky, S. Stovby, N. Maksyshko, V. Shapovalova [19], E. Kanaeva [20] and others are devoted to the improvement of decision-making methods in the economy based on the use of a fuzzy modeling methods.

The methodology for constructing a fuzzy model, including to obtain a qualitative assessment of an investment project for the development of an UTC, taking into account the concept of sustainable development, consists of the following stages:
- formation of a base for a fuzzy model input variables;
- fuzzification of input and output variables;
- formation of a fuzzy logic rules base;
- accumulation of conclusions based on fuzzy rules;
- defuzzification of the output variable (figure 1).

Method of investment projects evaluation for territorial communities is based on use of the constructed fuzzy model. The fuzzy model allows to bring the totality of quantitative and qualitative evaluations to a single quantitative scale: rating, which makes it possible to compare projects by different areas (economic, social and environmental).

A fuzzy model for evaluating the investment projects attractiveness is used to benchmark projects on the development of an UTC in line with the sustainable development concept. The general scheme of the decision-making method for choosing an investment project is presented in figure 2.

The Fuzzy Logic Toolbox Editor, a built-in application to Mathworks, is used to implement a fuzzy model for evaluating an investment project for the development of an UTC.

3 Results

A fuzzy model of evaluating the investment projects attractiveness for integrated territorial communities is built, based on the use of fuzzy logic and taking into account the sustainable development concept.

The first two stages of fuzzy model construction are done in parallel. In the first stage the variables and the set of their linguistic terms are defined, and in the second stage – the fuzzification – the sets of variable definition and the type of membership functions are specified.

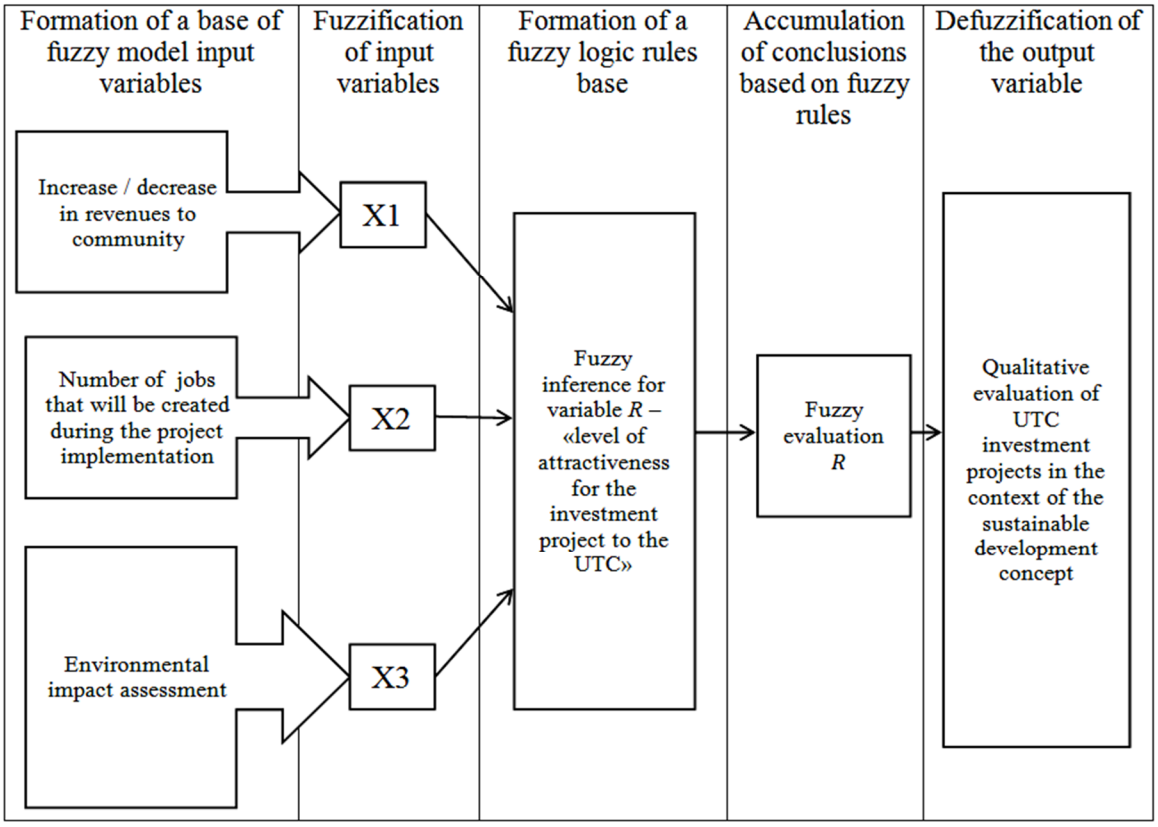


Fig. 1. The general scheme of fuzzy model construction for investment project evaluation to the development of an UTC.

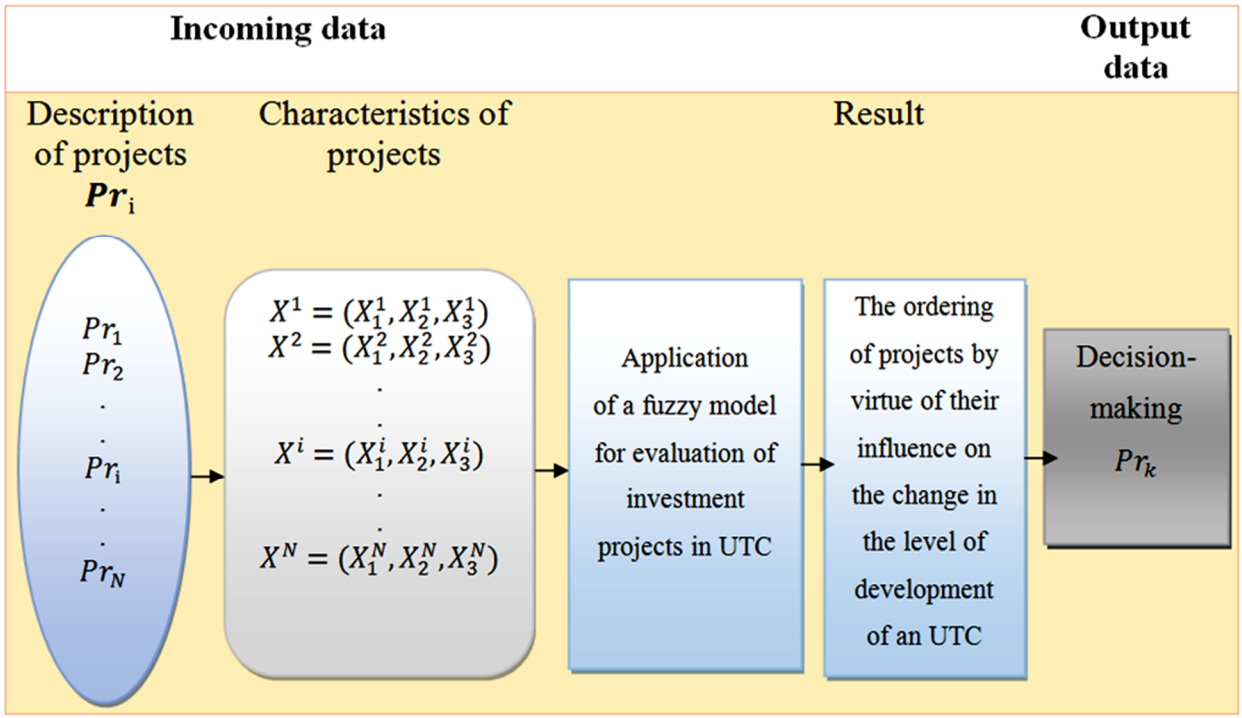


Fig. 2. The general scheme of the method of deciding on the choice of investment project to the development of an UTC.

Variable X_1 reflects the rate of increase / decrease in community budget revenues. This indicator characterizes the relative changes (%) in budget revenues resulting from the project implementation.

The variable X_1 is calculated by the formula:

$$X_1 = \frac{F_i}{F_{i-1}} \times 100\% , \quad (1)$$

where X_1 – economic growth (%);

F_i – the amount of budget revenues after project implementation (at time i);

F_{i-1} – the amount of budget revenues before the project implementation (at time i-1).

Based on the analysis of existing investment business projects, interval [70; 150] is chosen for the values set of variable X_1 ($X_1 \in$ [70; 150]). The 70% limit is explained by the fact that, despite the potential environmental and social benefits of the investment, the project will not be considered if its losses can exceed 30% of the community budget. The upper limit is set at 50% of all budget revenues and is 150. Variable X_1 is given by three linguistic variables (term-sets). Their fuzzification parameters are shown in table 1.

Table 1. Fuzzification of the Economic Growth variable (X_1).

Linguistic assessment	View membership function	Function options
Decrease	trapezoidal	[70;70; 90; 100]
Permanence	triangular	[93; 100; 107]
Increase	trapezoidal	[100; 120; 150; 150]

A visual representation of variable X_1 is shown in figure 3.

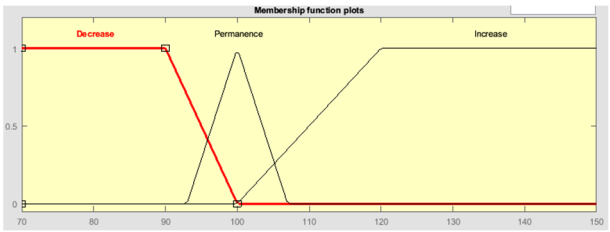


Fig. 3. Graphical representation for the term-sets of Economic growth variable (X_1).

The choice of the triangular membership function for linguistic assessment "Permanence" is explained by the fact that only the value 100 fully corresponds to the term "stable" and the value of the membership function μ of the linguistic variable "Permanence" at X_1 = 100 equals one ($\mu^{Permanence}$(X1=100)=1). When deviation from 100 in intervals [93; 100) and (100; 107] the membership function decreases linearly to zero.

The linguistic variables "Increase" and "Decrease" are better described by the trapezoidal function, since the membership functions μ are equal to 1 not only at one discrete value X_1, but at the interval $X_1 \in$[70; 90]: $\mu^{Decrease}(X_1)$=1 and $X_1 \in$[120; 150]: $\mu^{Increase}(X_1)$=1.

The next variable is X2 which takes into account the social inclusion from the project. Input variable X2 is estimated as a percentage reduction in community unemployment (calculated as the ratio of the jobs created number during the project to the total number of unemployed communities):

$$X_2 = \frac{W}{U} \times 100\% , \quad (2)$$

where X_2 – Social inclusion (%);

W – number of new jobs created during the project implementation;

U is total number of unemployed communities.

The value of variable X_2 is within $X_2 \in$[0; 100]. Thus, if no new jobs are created during the investment, then X_2 = 0, if the number of jobs created is equal to the number of unemployed communities, then X_2 = 100 (%). In case where the number of jobs exceeds the number of unemployed persons should be considered separately and are not the subject of this study, as they cover the issue of changing the social policy of the community regarding labor attraction.

The basic fuzzification parameters for variable X_2 are shown in table 2.

Table 2. Fuzzification of the Social inclusion variable (X_2).

Linguistic assessment	View membership function	Function options
Slight	triangular	[0;0; 20]
Medium	triangular	[10; 30; 50]
Significant	trapezoidal	[30; 60; 100; 100]

The visual representation of variable X_2 is shown in figure 4.

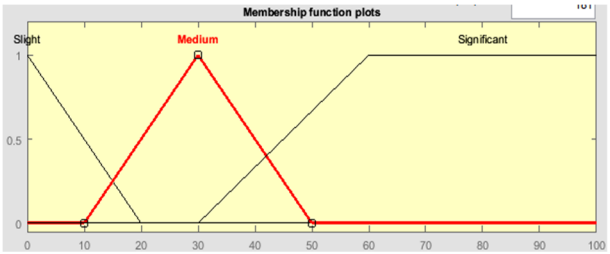


Fig. 4. Graphical representation for the term-sets of Social inclusion variable (X_2).

The variable X3 characterizes the environmental effect that the investment project has on the environment. The value of X3 is determined on the basis of expert evaluation, measured in points and is in the interval: X3ϵ [-100; 100]. That is, at the most destructive value of environmental impact X3 = -100, with neutral impact X3 = 0, and at the most positive X3=100. The basis for the determination of variable X3 can be the environmental impact assessment report conducted on the basis of Law of Ukraine No. 2059-VIII [15] or calculations, for example, by the method [12].

The basic fuzzification parameters for variable X_3 are shown in table 3.

A visual representation of the variable X_3 is shown in figure 5.

The application of the five linguistic variables and Gaussian membership functions is explained by the complexity of the procedure for formalizing

environmental impact assessment, which is determined only by expert opinion. The Gaussian type of membership function is analogous to the normal law of distribution for random variable. This law is the most inherent in natural environmental processes.

Table 3. Fuzzification of the Environmental protection variable (X_3).

Linguistic assessment	View membership function	Function options
Extremely negative	Gaussian	[-20; -100]
Negative	Gaussian	[15; -50]
Neutral	Gaussian	[10; 0]
Positive	Gaussian	[15; 50]
Extremely positive	Gaussian	[20; 100]

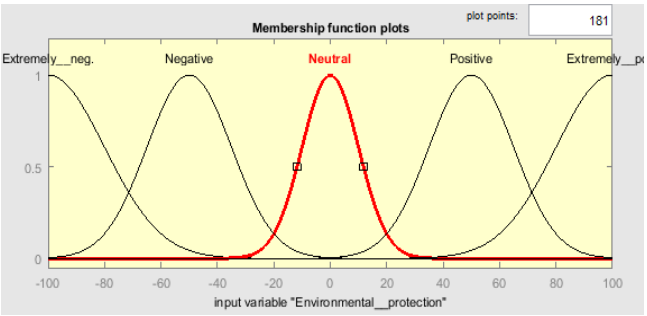


Fig. 5. Graphical representation for the term-sets of Environmental protection variable (X_3).

Using the three input variables that characterize the economic, social and environmental impact of the project, it is necessary to obtain an integrated investment rating - the output variable R, which indicates the level of attractiveness for the investment project to the UTC (measured in points). Let variable R is defined in the interval [0; 100], where R = 0 corresponds to an absolutely unattractive investment and R = 100 to an absolutely attractive investment. The main fuzzification parameters of the variable R are given in table 4.

Table 4. Fuzzification of the variable *R* – rating of investment attractiveness.

Linguistic assessment	View membership function	Function options
Slight	triangular	[0;0; 35]
Medium	triangular	[25; 50; 75]
Significant	triangular	[65; 100; 100]

A visual representation of the variable R is shown in figure 6.

The next stage is a building a fuzzy knowledge base and decision-making rules.

The rules are based on the following considerations. First, let's set the rules for the extreme values of X_3 - the environmental component. If the value of X_3 is "Extremely negative", then the investment rating will be low, regardless of the X_1 and X_2 values. This means that with significant damage to the environment, despite the possible high economic or social effect, the attractiveness of this project will be considered low.

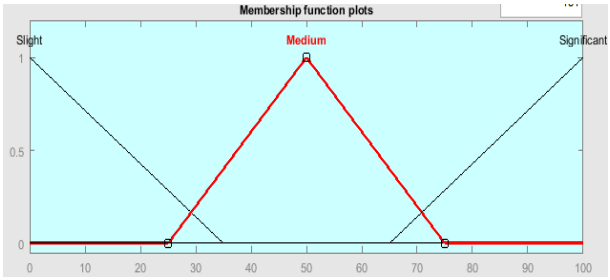


Fig. 6. Graphic representation for the term-sets of output variable *R*.

Accordingly, with the Extremely positive value of the environmental component, the benefit of the investment will be considered significant, regardless of the economic or social component. Recall that the negative economic effect is limited to 30% when determining the input value X1 (projects that lead to a decrease in community budget revenues by more than 30% are not considered).

Other rules of the fuzzy knowledge database are presented in the form of table 5.

Table 5. Knowledge base for variable *R* – rating of the investment attractiveness.

Variables		X3 (Negative)	X3 (Neutral)	X3 (Positive)
X1	X2	R	R	R
Decrease	Slight	Slight	Slight	Slight
Decrease	Medium	Slight	Slight	Medium
Decrease	Significant	Slight	Slight	Medium
Permanence	Slight	Slight	Slight	Medium
Permanence	Medium	Slight	Medium	Significant
Permanence	Significant	Slight	Significant	Significant
Increase	Slight	Slight	Significant	Significant
Increase	Medium	Medium	Significant	Significant
Increase	Significant	Medium	Significant	Significant

Based on the Table 5 and the assertions of extreme values of environmental effects generated 16 rules:

1. If (Environmental protection is Extremely negative) then (Rating is Slight).
2. If (Environmental protection is Extremely positive) then (Rating is Significant).
3. If (Economic growth is Decrease) and (Environmental protection is Negative) then (Rating is Slight).
4. If (Economic growth is Decrease) and (Environmental protection is Neutral) then (Rating is Slight).
5. If (Economic growth is Increase) and (Environmental protection is Positive) then (Rating is Significant).
6. If (Economic growth is Permanence) and (Environmental protection is Negative) then (Rating is Slight).
7. If (Economic growth is Increase) and (Social inclusion is Slight) and (Environmental protection is Negative) then (Rating is Slight).
8. If (Economic growth is Increase) and (Social inclusion is not Slight) and (Environmental

protection is Negative) then (Rating is Medium).

9. If (Economic growth is Permanence) and (Social inclusion is Slight) and (Environmental protection is Neutral) then (Rating is Slight).
10. If (Economic growth is Permanence) and (Social inclusion is Medium) and (Environmental protection is Neutral) then (Rating is Medium).
11. If (Economic growth is Permanence) and (Social inclusion is Significant) and (Environmental protection is Neutral) then (Rating is Significant).
12. If (Economic growth is Increase) and (Environmental protection is Neutral) then (Rating is Significant).
13. If (Economic growth is Decrease) and (Social inclusion is Slight) and (Environmental protection is Positive) then (Rating is Slight).
14. If (Economic growth is Decrease) and (Social inclusion is not Slight) and (Environmental protection is Positive) then (Rating is Medium).
15. If (Economic growth is Permanence) and (Social inclusion is Slight) and (Environmental protection is Positive) then (Rating is Medium).
16. If (Economic growth is Permanence) and (Social inclusion is not Slight) and (Environmental protection is Positive) then (Rating is Significant).

Mamdani fuzzy inference system is used to build the model. This choice is due to the lack of a statistical sample of quantified evaluation for the indicators under study, the qualitative nature of the variables X3 (environmental component) and R (rating of the investment project).

As a result of the model, it is possible to build a surface that gives a graphical idea of the project rating depending on the input indicator values (fig. 7).

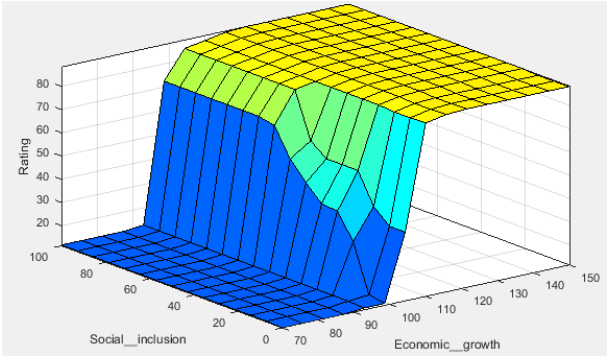
The constructed model can be applied to support decision-making in the development and justification of a strategic plan for the development of united territorial communities.

To verify the model, let's test it on the example of Veselovsky United Territorial Community of Veselovsky district of Zaporizhzhia region. According to the official site of Veselivska UTC, the population (excluding preschool and school-age children) is 10 640 people, and the amount of income (estimated) of the territorial community is 12.679 million UAH [22]. According to the State Statistics Service of Ukraine, the average unemployment rate in the Zaporizhzhya region is 9.9% among the population aged 15-70 years [23]. Then the number of unemployed Veselovskaya OTG is approximately 1,053 persons.

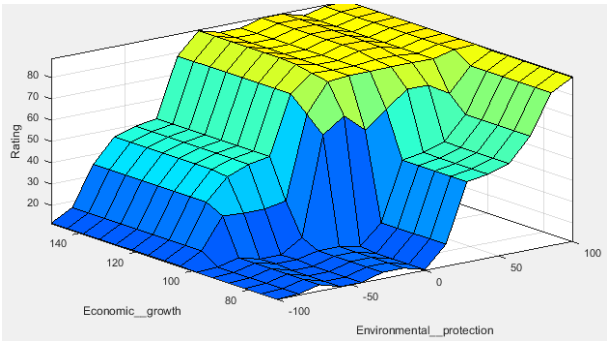
Consider two alternative investment projects for the development of the territorial community: the traditional activity for Ukrainian farmers is sunflower cultivation and the innovative approach is the construction of a solar power plant.

Let’s look at project characteristics in more detail.

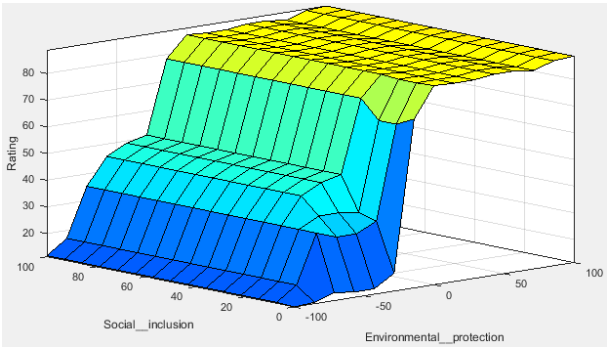
Project 1 – Sunflower cultivation.



a)



b)



c)

Fig. 7. The output surface for the variables: a) Social inclusion (X_2) and Economic growth (X_1); b) Economic growth (X_1) and Environmental protection (X_3); c) Social inclusion (X_2) and Environmental protection (X_3).

Sunflower growing is a profitable business, it is the most profitable oilseed crop in our country. The basic data for the calculation were obtained from the source [24], in particular, the results of sunflower cultivation of LLC “Dokuchaevsky Chernozem”, Karlovsky district of Poltava region.

It is known that the territorial community is considering the use of 20 hectares of land owned by it.

The costs of growing and harvesting in this case amount to 280 thousand UAH, the increase in cash flow from the project is also 280 thousand UAH. The number of jobs created is 10.

The cultivation of sunflower is associated with such negative effects as the depletion and drying of the soil, increased water and wind erosion [25]. The cultivation of sunflower is associated with such negative effects as

the depletion and drying of the soil, increased water and wind erosion. Considering that the problem of soil depletion and erosion can be solved, and the problem of drying is smoothed by the correct cultivation of land, the expert assessment of environmental impact is 10 points.

Thus, the input variables of the sunflower cultivation project are:

X_1 = 102.2%;

X_2 = 1%;

X_3 = -10 points.

The result of the evaluation for project 1 in the defuzzification stage is shown in figure 8.

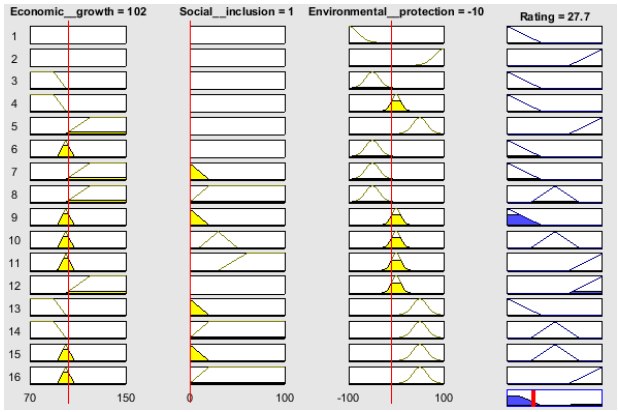


Fig. 8. Rule Viewer for sunflower growing.

According to the results of the evaluation, the attractiveness of this investment is 27.7 points out of 100 possible.

Project 2 - construction of a solar power plant.

A solar grid power plant is used to sell electricity to the grid at a "green" rate.

Suppose that solar power plant wants to build on a plot of 20 ha.

The cost of its construction is $8 million, the profitability of the project will be 25.3%, the payback period of the project – 5 years. As a result, we receive $2.078 million revenues, 25 jobs, and a positive environmental impact assessment at 50 points (used for calculations [26]).

However, it should be noted that the territorial community does not have the financial resources to implement such a large-scale, in terms of initial investment, project, so the implementation of this project is possible only with the participation of the investor. If the community finds an investor and receives only land and taxes, the annual income will be 250,000 UAH.

Thus, the input variables of a project involving an investor to build a solar power plant are:

X_1 = 101.9%;

X_2 = 2.4%;

X_3 = 50 points.

The results of the evaluation of project 2 in the defuzzification step are shown in figure 9.

The attractiveness of the project for the construction of a solar power plant with the involvement of the investor is 54.5 points out of 100, which is almost twice better than the project for growing sunflower.

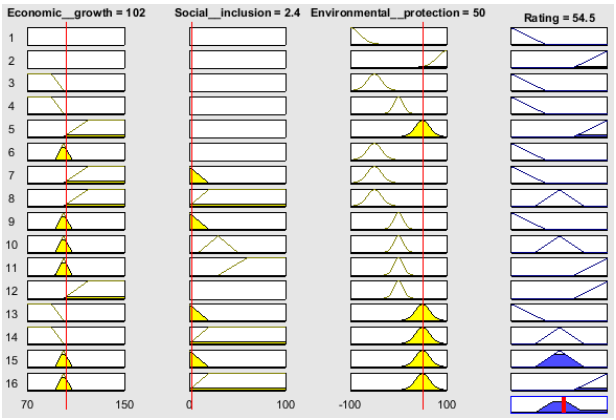


Fig. 9. Rule Viewer for attracting an investor to build a solar power plant.

Thus, the results of applying the fuzzy logic method and deciding on the choice of an investment project for the development of the UTC have shown that Project 2 is the most beneficial.

Although the budget of the community does not allow allocating sufficient amount of money for the construction of its own solar power plant, the decision to build a solar power plant with the involvement of investors is more advantageous than the cultivation of sunflower. Of course, the community income will be less than if the power plant belonged to the community, and the number of jobs and the share of electricity generated from renewable sources will remain unchanged.

4 Conclusion

The concept of sustainable development at the level of territorial communities aims at harmonious and balanced management of their resources in order to ensure social, economic and ecological development of the community, increase its economic potential, create a complete living environment for modern and future generations.

The achievement of this goal is facilitated by the decentralization reform, which requires the formation of an effective system for public authority. The powers delegation to the local level activates the economic activity of local self-government bodies, motivates them to use their existing potential effectively and rationally, to take management decisions to find alternatives and additional opportunities for increase the competitiveness of territorial communities.

Decision-making at the territorial community level to provide additional services to local residents, improve their living conditions, create a full living environment is of central importance in the implementation of the sustainable development concept. At the same time, important aspects of this activity are its publicity, transparency, interests' coherence of the authorities, business and the public.

Managing the development of a territorial community requires a constant search for a balance

between its economic, social and environmental components, involving all stakeholders in the decision-making process; flexibility and effectiveness of management actions.

All these problems and tasks will necessitate the widespread use of new digital technologies (digitization) to optimize and automate decision-making processes, ensure transparency of decisions, and improve communication with community members. There is a need to develop and improve decision support systems which accumulate databases that available in the community and databases of models that address management challenges.

In this work, a fuzzy model of investment project evaluation is developed and substantiated. It is aimed at the development of a territorial community, based on taking into account its qualitative assessments in terms of the main components of the sustainable development concept. This model makes it possible to give a "soft" qualitative evaluation of the investment project under consideration, while taking into account not only its quantitative but also qualitative characteristics.

The model has the potential for further improvement due to the detailing of the process of evaluating the component indicators, the formation of a branched tree of goals, the extension of gradations (the number of terms) of qualitative estimates, determining the benefits of each indicator for a particular community, etc.

However, the proposed model has already been the basis of the decision-making method for selecting investment projects for the territorial community' development, based on a comparative analysis of their qualitative assessments.

The proposed method has been tested for making decisions on the choice of investment project based on the data of the Veselivska United Territorial Community of Veselivsky District of Zaporizhzhia Region.

As a result of applying the fuzzy evaluation model, a comparative analysis of two investment projects - Sunflower Growing and Solar Power Plant Construction - was made. The results of the calculations showed that all the parameters of the model are correctly defined and all the necessary information for their calculation is available. The management of the territorial community confirmed the expediency of deciding on the choice of investment project, which was obtained as a result of the application of the developed method (construction of a solar power plant with the involvement of investors).

The use of standard mathematical software (Fuzzy Logic Toolbox application) creates opportunities for model implementation and its application in the development of territorial decision support systems to quantify decisions and to make variant calculations for choosing the best investment options.

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Efficiency forecasting for municipal solid waste recycling in the context on sustainable development of economy

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Abstract. Ukraine's further economic growth should be directed by Government Sustainable Development Strategy for harmonization of economy, environmental and social protection. One of the important modern problems is pollution by waste. The feasibility of introducing an eco-project for the municipal solid waste recycling is substantiated at the present research. The complex mathematical model of profit forecast is developed, which shows the tariffs influence on profitability of eco-project on construction of the plant for municipal solid waste recycling in Poltava region of Ukraine. The authors determine and analyse the dependences of the expected eco-project revenue from the change in tariffs for waste management services for each of the consumer categories. Two scenarios of economic development (inertial and innovative) are compared and resulted that the both scenarios have environmental and economic effect, so they are investment attractive. Emphasis is placed on the shortcomings and gaps of the existing tariff policy. The paper demonstrates lack of incentives for the development of business recycling under the existing tariff policy, so to establish a single tariff is proposed uniting the services cost for the removal, sorting, processing and disposal of the waste and also without dividing by consumer categories.

1 Introduction

The choice of Ukraine as a point for further economic growth of the Sustainable Development Strategy pushes business, politicians, the scientific community, ordinary citizens to rethink the traditional model of economy and the need to transform it from linear to circular, based on the principle of sustainable development – "take, make, reuse". The linear model of economy is based on the principle of "take, make, waste". Whereas this linear model is the dominant in Ukraine since the Industrial Revolution. It has led to a number of serious problems, among which is the most magnitude and significance problem is Municipal Solid Waste (hereinafter – MSW) generation, which does not only hinder the socio-economic development of the country, but also leads to environmental destruction [1, p. 505].

According to the Law of Ukraine "On Waste" dated 05.03.1998, No. 187/98 [2] (as amended on 01.05.2019) (hereinafter – the Law of Ukraine, No. 2189-VII) formed in the course of human life and activity in residential and non-residential buildings and are not used at their place of accumulation [2]. The Law, No 2189-VII is fundamental, based on its approach the approach foreseen in Directive 2008/98/EC of the European Parliament and of the Council on waste [3].

As of the end of 2018, more than 12.5 billion tonnes of MSW hazard classes I, IV, or 21.5 thousand tonnes per km^2 of state territory have been accumulated in designated areas in Ukraine [4], making the country one of the world's leaders in terms of waste. Landfill and disposal services at the polygons and landfills, which at the end of 2018 in Ukraine calculated more than 5.5 thousand units with a total area of over 9 thousand hectares, of which 305 (5.6%) are dominant overloaded, and 1.6 thousand units (30%) do not meet environmental safety standards [5]. The most successful way to solve this problem, from the experience of European countries, is to move from the traditional to the circular model of the economy, in which waste is perceived not as garbage, but as secondary resources [6].

"Sub-regional Waste Management Strategy" (hereinafter referred to as the Strategy) [7], developed for the Poltava Oblast for this purpose by European experts with the support of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in the framework of the international project "Governance Reform in Eastern Ukraine" (PN 11-2129.2-001.00). The strategy envisages the implementation of an eco-project for the construction of a modern landfill and five sorting stations, as well as a waste recycling plant.

The feasibility of implementing the eco-project is substantiated by:

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- amendments to the Law of Ukraine No. 2189-VII [2] on the prohibition of the disposal of unprocessed waste;
- the need to protect fertile soils from contamination and to prevent the further expansion of the areas of the bacteria dumpsites of landfills;
- the absence of any solid waste processing enterprises in the region.

The success of its implementation is hampered by low tariffs on waste management services that do not create incentives for business recycling.

It is convinced that the waste recycling business is economically and environmentally effective. We conducted a comprehensive study of eco-project management effectiveness for the construction of solid waste processing plant to prove this statement.

2 Literature review

Nowadays, Ukraine is undergoing a complex process of socio-economic transformation, in which it is of utmost importance for society to realize the significance of the Sustainable Development Strategy chosen by the EU countries and Ukraine, which should unite the society in deciding three basic interconnected challenges – economic growth, environmental protection and social protection for all members of the society [8].

The focus is on sustainable development goals and the strategic framework for its providing in Ukraine, which will ensure macroeconomic stability, environmental balance and social cohesion in practice, and will serve as a common basis for further transformations [9]. Ukraine's place in the world ranking according to the criteria of the Index of Sustainable Development (ISD) is analysed in [10]. The main strategic stages of ensuring sustainable development in Ukraine are proposed in [10].

Waste has become an environmental problem in Ukraine. As plastic consists of harmful pollutants, it causes a significant threat to atmosphere. The most serious long-term effects of plastic pollution are groundwater, land and air pollutions, threat to animals, disturb of the food chain [11]. The issue of waste disposal is being discussed and it is obvious that at every stage of the process, it is possible to make money from waste [12]. Waste disposal includes reducing the local pollution and saving landfill space.

During the last two decades, EU legislation has put increasing pressure on member countries to achieve specified recycling targets for MSW [13]. Moreover, paper [13] compares MSW management practices in various EU countries to identify the characteristics and key issues from a waste management. Therefore, it was concluded that the waste recycling is a multi-disciplinary problem that needs to be considered at different decision levels simultaneously [13].

Management of MSW is a major challenge for most of the urban local authorities in developing countries primarily due to the rising of urban population and per capita waste generation rate [11]. Improper handling of MSW will create the city unsuitable for living.

The paper [14] illustrates an overview of the past and present MSW management strategies in China. A comparison is made with other developed and developing countries to identify and analyze the existing problems and evaluate some effective suggestion to overcome the limitations. Increase waste recycling and proper taxation system for MSW disposal are essential to improve MSW management in China [14].

The economic and environmental aspects of sustainability are considered on the waste recycling process in Malaysia [12], Iran [15], India [11], Canada [16]. The equilibrium strategies are obtained and various managerial insights are revealed, moreover, more the recyclability degree of the waste leads to higher profits for the members [15]. Economic outputs, expenditure and profits, and business sizes for both public and private waste services were studied [16].

Economy of the society makes great influence on the waste situation. Some of the socioeconomic variables are significantly correlated with solid waste generation [12].

The results of [17] show that the specific charge policy can improve the performance of residents' separation behavior, which is a more effective way to reduce the MSW and increase the collection rate of domestic recyclable resources. To resolve the issue of the urban waste management, it is necessary to balance the profit of charge point of agents in the system [17]. This shows the relevance of development the model, which indicates the influences of waste management tariffs on the profit from waste recycling in Ukraine.

Ackermann [18] acknowledged the importance of recycling in the face of economic growth and proved its effectiveness if it created a favourable environment for eco-projects. Rifkin [19] emphasized the importance of recycling in the industrial revolution and argued for the need to take into account both environmental and economic efficiency during deciding on the implementation of eco-projects. Tkachenko, Levchenko, Pozhuieva, and Shupryna [20] underlined the need to make the link between green growth of agribusiness volumes and its impact on the environment, while emphasizing the importance of making significant decisions during implementing eco-projects through eco-mathematical modelling analysis.

Focusing on the issues of assessing the profitability of eco-projects, Dovha [21] substantiated her own approach to the classification of indicators for the assessment of the ecological and economic efficiency of household waste recycling in Ukraine. Bobylev, Goryacheva and Nemova [22] concentrated on a project-based approach to developing household waste recycling and evaluating its effectiveness. Scientists emphasize the need to reconcile the interdependence of economic and environmental interests to address ways of adapting businesses to new business conditions. The necessity of application of economic and mathematical modelling by the method of correlation and regression analysis in estimating the expected effect of eco-projects is substantiated in [12, 17, 22].

3 Calculation methodology

Correlation and regression analysis are the main one in the study of the relationship of phenomena and therefore it is a necessary modern tool in engineering and economic research. This is a quantitative method for determining the density and the type of the mathematical function in a causal dependence between variables. Naturally, it is constantly developing and improving for different applied models [23].

The method of least squares is often used to generate estimators and other statistics in regression analysis. It was shown how difficult questions could be answered by developing simple models with simple interpretation of parameters for diversity of applications [23, 24].

The first attempts to set up a waste recycling business in Ukraine were unsuccessful for reasons such as a lack of recyclables and the lack of economic incentives for MSW recycling. Therefore, when deciding on the implementation of eco-projects for waste recycling, first, the question arises of the generation of waste at medium-term and long-term horizons.

The calculation of the expected volumes of MSW was performed according to the methodology stipulated by the Order of the Ministry of Housing and Communal Services of Ukraine "On Approval of the Rules for Determining the Standards of Provision of Services for the Removal of Household Waste" No. 309, July 30, 2010 (with changes and additions) [25]. It is based on:

- population change projections, determined by foresight methodology;
- prospects for economic development of territories and rates of growth of incomes of the population;
- waste generation standards, calculated taking into account the area of residence and improvement of house.

Projections of population change for the period up to 2040 are determined according to the data of the Demographic forecast of population development in Poltava for the period up to 2050, carried out within the framework of the project "Integrated Urban Development of Ukraine" No. 2015.2071.7.001 [26] by the method of transportation of age group.

The demographic forecast [26] is based on a scenario approach, which envisages two scenarios of economic development in the Poltava sub-region:

- inertial, which is expected to gradually reduce the population due to: falling fertility rates and reducing life expectancy, negative external migration, etc.;
- an innovative one that is expected to slow down the population and, starting from 2030, gradually grow, thanks to the development of industry and internal "village-city" migration [26].

The calculation of the expected volumes of MSW is performed according to the standards of formation of MSW, provided by IBN B.2.2-12:2018 "Territory planning and development" [27] and [28] in Table 1.

In addition, the data is presented according to the results of the study of the morphological composition of MSW, carried out within the framework of the GIZ project under the Comprehensive Program for Solid Waste Management in Poltava region for 2017-2021 [28] in Table 2.

The calculation of the expected income from the provision of solid waste management services was made taking into account the tariff forecasts determined by the Law of Ukraine "On Housing and Communal Services" of 09.11.2017 No. 2189-VIII [29] by three categories of consumers as:

I – the population;
II – budgetary institutions;
III – other consumers.

Table 1. Norms for municipal solid waste generation.

Indicators	Objects for the formation of MSW	Quantity, kg	Annual rate of formation of MSW on the settlement unit, m^3
Average in the settlement with the account of pendulum migration	1 person	250-350	1.8-2.5

Tariff estimates, in contrast to the existing tariffs (which include only the cost of removal and disposal of waste), are determined taking into account the costs of each of the waste management services: removal, sorting, processing and disposal.

The separate collection costs by collected (sorting of useful components of household waste) are not taken into account when setting prices/tariffs for a household waste service in accordance with the amendments made to the Order of formation of tariffs for services for the removal of household waste, approved by the Cabinet of Ministers of Ukraine on 26.07.2006, No. 1010 [30] by the Cabinet of Ministers of Ukraine "On Amendments to certain CMU Resolutions" of March 27, 2018, No. 318 [31]. Estimated revenue from MSW recycling has been calculated taking into account the morphological composition of the rubbish (see Table 2) and the expected volume of household waste for the period up to 2040.

Particular attention is paid to plastic waste, since according to the Draft Law of Ukraine "On Waste Management" dated 22.10.2019, No. 2207-1 [32], submitted by the Ministry of Ecology and Natural Resources of Ukraine for consideration by the Parliament, plastic waste is secondary resources.

The expected volume of plastic waste is calculated based on the estimated volume of waste and the percentage of plastic determined from the GIZ morphological studies.

The expected level of suitability of plastic waste for recycling has been established, taking into account the identification of plastic waste by ISO 1043 code "Plastics – Symbols and abbreviated terms" [33].

The prices of clean PET flakes and secondary crystalline granules, as well as the volume of plastic waste (recoverable), determined by the expected future price of the sale of secondary resources.

Let's consider the time series of the average tariff for MSW management services for population (y_1, UAH/m^3) based on the statistics on Poltava sub-region [4].

The statistics is presented in Table 3 for each of the categories of service consumers, and above all for consumers of Group I – population. Thanks to smoothing the levels of the time series for further forecasting, we find an analytical dependence of the nonlinear change in the indicator by years (x).

It was proposed to consider the equation that describes this model as a quadratic regression, whose coefficients are found by the least squares method with the prior linearization

$$\hat{y}_1 = -3861.39 + 0.00096 \cdot x^2. \quad (1)$$

The next formula is used in order to calculate the expected revenue from the provision of MSW providing services for the population of Poltava sub-region D_{tn}, UAH million

$$D_{tn} = y_1 \cdot 10^{-6} \cdot x_1 \cdot x_2. \quad (2)$$

where x_1 is the MSW rate per person per year, m^3/year, which was taken from [26]; x_2 – the size of population [27].

We also develop a model of linear change over the years of the average tariff for MSW management services (y_2, UAH/m^3) for the purpose of full estimation of the expected revenues for the provision of MSW management services for the second category of consumers – budgetary institutions of the Poltava sub-region.

We propose to consider the equation that describes this model as a linear regression, for which the following coefficients are found

$$\hat{y}_2 = -6605.79 + 3.30 \cdot x. \quad (3)$$

We will assume that in the inertial scenario of the economy development of the Poltava sub-region: x_3 – the volume of creation of MSWs by budgetary institutions relative to 2018 will increase by 10% and on average $x_3 = 140741.23 \cdot 1.1 = 154815.35$ (m^3) – and long-term horizons will remain constant in order to calculate D_{tb} – the expected revenue from the provision of MSW management services for budgetary institutions, UAH million.

Hence

$$D_{tb} = y_2 \cdot 10^{-6} \cdot x_3. \quad (4)$$

At the same time, we will develop a model of linear change over the years of the average tariff for MSW management services (y_3, UAH/m^3) for the last category of consumers – other consumers of services in the field of MSW management in the Poltava sub-region.

It was proposed to consider the equation that describes this model as a linear regression, whose coefficients, similar to the previous models, are found by the least squares method

$$\hat{y}_3 = -6305.53 + 3.15 \cdot x. \quad (5)$$

The correlation coefficients for the linearized model (1) – r = 0.88, for model (3) – r = 0.89 and for (5) – r = 0.88 are quite close to one, indicating that there is a close relationship in all the proposed models.

The Student's t-test showed that the calculated criterion t = 5.18 for (1), t = 5.45 for (3) and t = 5.26 for (5) is larger than the tabular t_{cr} = 2.306, found at the significance level α = 0.05, that is, with 95% reliability, we can assume that the regression coefficients are found correctly.

The Fisher's test verifies that the calculation criterion F = 26.78 for (1), F = 29.74 for (3) and F = 27.71 (5) is larger than F_{cr} = 5.32 found at α = 0.05, which gives reason to ascertain the adequacy of the proposed models with statistical data.

Designating D_{ti} as revenue from the provision of MSW management services for other institutions and D_t as the aggregate revenue from the provision of MSW management services, depending on tariff changes, we have

$$D_t = D_{tn} + D_{tb} + D_{ti}. \quad (6)$$

Table 2. The composition of MSW by categories of houses, %.

Waste components	Poltava multi-storey buildings	Poltava private houses	Cities with more than 5000 multi-storey buildings	Cities with more than 5000 private houses	Large population settlements (1000-5000 inhabitants)	Small settlements (smaller than 1000 inhabitants)
Organic waste	43.3	37.1	29	19	14	19.3
Paper	9	7	9	7	8	1.4
Plastic	12	13	13	13	13	11
Glass	11	18	15	21	17	24
Metal	1.1	1.2	0.8	1.1	2	3.8
Others	23.6	23.7	33.2	38.9	46	40.5
Total	100	100	100	100	100	100

Table 3. Tariffs for utilities in the field of MSW management within the Poltava sub-region, UAH/m^3 with ValueAddedTax (VAT).

Average approved tariff of MSW providing services for	Years, x									
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
population with VAT, UAH/m^3, y_1	12.40	18.50	29.29	29.29	29.29	29.29	30.20	30.20	49.52	58.35
budgetary institutions with VAT, UAH/m^3, y_2	18.60	24.70	35.93	35.93	35.93	35.93	36.10	36.50	52.96	56.73
other consumers with VAT, UAH/m^3, y_3	27.10	34.10	41.50	41.50	41.50	41.50	41.80	43.20	59.86	63.83

It was developed multivariable nonlinear regression for forecasting D_t as a model for the impact of tariff policy on the value of revenue from the provision of MSW management services, which looks like

$$D_t = -65.045 + 540.392 \cdot \left(\frac{y_1}{10^2}\right)^2 + 797.251 \cdot \frac{y_2}{10^2} + 26.115 \cdot \left(\frac{y_3}{10^2}\right)^{-0.33} \quad (7)$$

The regression coefficients were found after linearization using the least squares method in matrix form, with preliminary smoothing of the initial data as time series.

The determination coefficient is quite close to one: $R^2 = 0.685$, and in addition the calculation criterion $F = 25.344$ is greater than the table criterion $F_{cr} = 4.76$, found at the significance level $\alpha = 0.05$, which confirms the adequacy of the proposed model with statistical data.

Let's create a model of nonlinear change of tariff threshold of availability of MSW providing services MSW (y_{11}, UAH/m^3) for the population of Poltava sub-region by years (x). We propose to consider the equation that describes this model as a quadratic regression, the coefficients of which are found by the method of least squares, with preliminary linearization

$$\hat{y}_{11} = -15024.54 + 0.00373 \cdot x^2. \quad (8)$$

It is close to unit, indicating a close relationship for a linearized model $r = 0.9$. The calculation criteria $t = 5.76$ and $F = 33.23$ are larger than the table values, i.e. with 95% reliability, we can assume that the regression coefficients are found correctly and the proposed model is adequate for the statistics.

4 Results and discussion

The values are summarized in Table 4 which were calculated by (1) – (8) for the period 2020-2040.

The regression graphs of (1) – a solid, and (8) – a dotted lines, together with the corresponding statistics – points, are shown in Fig. 1.

The graphs make it possible to observe the projected increase in tariffs on MSW management for the population at the current rate of growth, provided that tariffs are increased to the level of the tariff threshold of service availability, which will also increase in proportion to the average income per household.

Currently, the tariff threshold for accessibility of services to the population is almost in 3.8 times higher than the tariff set by the local self-government bodies of Poltava sub-region at the end of 2018. Therefore the risk of late payment of consumed MSW management services in the medium and long term horizons is expected, it will increase by almost 1/3, i.e. it will reach the level of 17.9%.

Table 4. Forecasting data of the MSW recycling eco-project for the period 2020-2040 – the inertial economic development scenario of Poltava sub-region.

Index	Years				
	2020	**2025**	**2030**	**2035**	**2040**
Population forecast, persons, x_2	453049	452235	440930	429907	419160
Expected formation of MSW, m^3 person, x_1	1.92	2.05	2.13	2.21	2.38
Volume of MSW formation by population, m^3, x_1x_2	869854.1	927081	939180	950094	997600
Tariff forecast for MSW providing services per person with VAT, UAH/m^3, y_1	56.80	76.22	95.69	115.21	134.78
Revenue from the providing services to the population, UAH million, D_{tm}	49.4	70.7	89.9	109.5	134.4
Risk of delay with payment, UAH million	5.8	8.3	10.5	12.8	15.8
Volume of MSW formation by budgetary institutions, m^3, x_3	154815.3	154815.3	154815.3	154815.3	154815.3
Tariff forecast for budgetary institutions with VAT, UAH/m^3, y_2	58.3	74.8	91.3	107.8	124.3
Revenue from the providing services to budgetary institutions, UAH million, D_{tb}	9.0	11.6	14.1	16.7	19.2
Volume of MSW formation by other consumers, m^3	81123.24	48872.18	103556.5	182389.9	237608.2
Tariff for other consumers with VAT, UAH/m^3, y_3	64.1	79.8	95.6	111.3	127.1
Revenue from providing services to other consumers, UAH million, D_{ti}	5.2	3.9	9.9	20.3	30.2
Revenue from providing services according to the MSW, depending on tariffs, UAH million, D_t	63.6	86.2	113.9	146.5	183.8
Volumes of formation of plastic, m^3	110993.4	118295.6	119839.5	121232.1	127293.9
Volumes of plastic formation, t	18646.89	19873.67	20133.03	20366.99	21385.37
of which are subject to processing, t	17155.1	18283.7	18522.3	18737.6	19674.5
Production volumes of finished goods, t	17155.1	18283.7	18522.3	18737.6	19674.5
including pure PET flakes, t	13037.88	13895.61	14076.95	14240.58	14952.62
secondary crystalline granules, t	4117.22	4388.09	4445.35	4497.02	4721.88
Price of pure PET flakes, thousand UAH/t	21.5	23.6	25.8	28.3	31.0
Price of secondary crystalline granules, thousand UAH/t	27.0	29.5	32.3	35.5	38.9
Revenue from the sale of finished goods, million, UAH	391.4	457.3	506.8	562.6	647.2
including pure PET flakes, million, UAH	280.3	327.9	363.2	403.0	463.5
secondary crystalline granules, million, UAH	111.1	129.4	143.6	159.6	183.7
Revenue from electricity supply, million, UAH	122.5	130.6	132.3	133.8	140.5
Total revenue, million, UAH	577.5	674.1	753	842.9	971.5

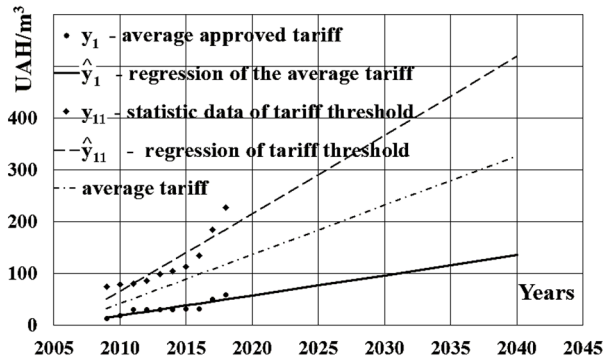

Fig. 1. Comparison of the existing tariffs of MSW providing services for population and their threshold.

Let's calculate the average arithmetic between the forecast tariff for the previous scenario and the tariff threshold for the availability of services (Fig. 1 the graph of which is shown by a dashed dotted line). The average tariff would be used for estimation of the profitability of the eco-project for recycling plastic waste for the period 2020-2040 under the innovative scenario of economic development of the Poltava sub-region tariff for the provision of MSW management services,

Let's consider the impact of different tariffs (one by one) on the income D_t (Fig. 2) under the condition of constant of other tariffs using the multifactor nonlinear model (7). We put constant the tariff for budgetary institutions at the level of y_2 = 60 UAH/m^3 and the tariff for other consumers of solid waste management services at the level of y_3 = 65 UAH/m^3.

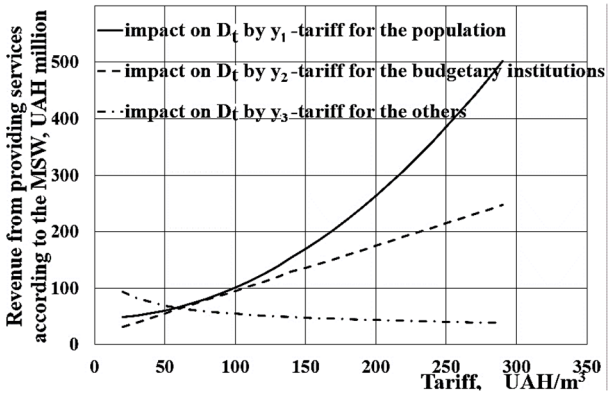

Fig. 2. Tariffs' impact on the revenue from providing services according to the MSW.

Let's study the impact of changing of the tariff on MSW management for population y_1 on the profitability of waste recycling eco-project, which is shown as a solid line in Fig. 2. The tariff for budgetary institutions and the tariff for other consumers were considered as constants at the level of y_2 = 60 UAH/m^3 and at the level of y_3 = 65 UAH/m^3. The dotted line in Fig. 2 characterizes the impact of the tariff change for budgetary institutions y_2 on the profitability of the waste recycling eco-project, when the next tariffs were considered as constants at the levels of y_1 = 55 UAH/m^3 and y_3 = 65 UAH/m^3. The dashed dotted line in Fig. 2 allows us to observe the impact of the tariff change for other consumers of y_3 on the profitability of the waste recycling eco-project, y_1 = 55 UAH/m^3 and y_2= 60 UAH/m^3. The negative free coefficient in (7) shows that, the waste recycling enterprise will losses suffer if the tariffs are reduced to zero.

We construct the appropriate surface (Fig. 3) to study the impact on the expected income of a MSW recycling eco-project at the same time as two factors – the impact of changing of the tariffs on MSW management services for the population y_1 and for budgetary institutions y_2, taking into account the constant tariff y_3 = 65 UAH/m^3 according to the model (7).

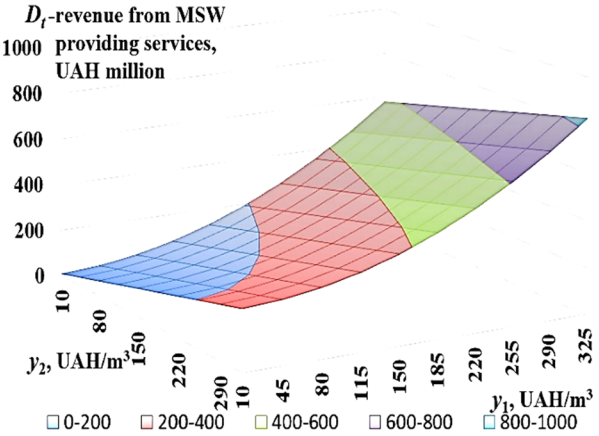

Fig. 3. The surface of the tariffs' impact on the revenue from providing services according to the MSW.

The calculated predictive values for the expected income from recycling MSW Eco-Project by (1) – (8) for innovative scenario of economic development for Poltava sub-region for the period 2020-2040 years are summarized in Table 5.

The average tariff for MSW providing services for the population, calculated as the average arithmetic mean the value of projected tariffs for the population in the previous scenario and the tariff threshold for the availability of services in the medium and long-term horizons will increase approximately 2.4 times, which at the same time requires an increase in tariffs and for the consumer in other categories.

According to the innovation scenario of the Poltava sub-region's economic development, the recycle of the eco-project on waste recycling is accelerated by almost 20% due to exceeding the level of profitability in comparison with the expected revenue under the inertial scenario of the development of the sub-regional economy.

However, in both inertial and innovative scenarios for the development of the economy of the Poltava sub-region, the eco-project for municipal waste recycling is accompanied by both an environmental and economic effect, which makes it an investment attractive, providing a "green" economic growth of the sub-region.

The results obtained are novel and unfortunately cannot be compared with known information due to the different conditions of project implementation. Thus, a similar project is being implemented by the European Union for the Territorial Cooperation with Limited Liability of TISA in the Transcarpathian region, but due to its specific territorial location and special geographical

features, it is not appropriate to use such areas of landfills as in the Poltava region. As for foreign projects, they are enough large-scale. The present work shows that small recycling processing plants with full self-financing are more acceptable to Ukrainian territorial communities.

Table 5. Forecasting data of the MSW recycling eco-project for the period 2020-2040 – the innovative economic development scenario of Poltava sub-region.

Index	Years				
	2020	**2025**	**2030**	**2035**	**2040**
Population forecast, persons, x_2	453049	452235	465802	507722	543263
Expected formation of MSW, m^3 person, x_1	1.92	2.05	2.13	2.21	2.38
Volume of MSW formation by population, m^3, $x_1 \cdot x_2$	869854.1	985872.3	1113267	1274382	1510271
Tariff forecast for MSW providing services per person with VAT, UAH/m^3, y_1	135.95	183.43	231.03	278.75	326.58
Revenue from the providing services to the population, UAH million, D_{tn}	118.26	180.84	257.20	355.23	493.22
Risk of delay with payment, UAH million	13.9	21.2	30.2	41.7	57.9
Volume of MSW formation by budgetary institutions, m^3, x_3	154815.3	154815.3	154815.3	154815.3	154815.3
Tariff forecast for budgetary institutions with VAT, UAH/m^3, y_2	139.72	180.18	220.59	260.97	301.33
Revenue from the providing services to budgetary institutions, UAH million, D_{tb}	21.63	27.89	34.15	40.40	46.65
Volume of MSW formation by other consumers, m^3	453013.2	619928.0	789083.8	933480.9	1010504
Tariff for other consumers with VAT, UAH/m^3, y_3	153.39	192.17	230.85	269.49	308.10
Revenue from providing services to other consumers, UAH million, D_{ti}	54.82	96.71	150.27	207.52	250.18
Revenue from providing services according to the MSW, depending on tariffs, UAH million, D_t	194.71	305.44	441.62	603.15	790.05
Volumes of formation of plastic, m^3	110993.4	125797.3	134467.8	137688.9	148687.8
Volumes of plastic formation, t	18646.89	21133.95	22590.59	23131.74	24979.55
of which are subject to processing, t	17155.14	19443.23	20783.34	21281.2	22981.19
Production volumes of finished goods, t	17155.14	19443.23	20783.34	21281.2	22981.19
including pure PET flakes, t	13037.91	14776.85	15795.34	16173.71	17465.7
secondary crystalline granules, t	4117.23	4666.38	4988	5107.49	5515.49
Price of pure PET flakes, thousand UAH/t	22.0	24.1	26.4	29.0	31.7
Price of secondary crystalline granules, thousand UAH/t	27.5	30.1	33.0	36.2	39.7
Revenue from the sale of finished goods, million, UAH	400.06	496.58	581.6	653.93	772.63
including pure PET flakes, million, UAH	286.83	356.12	417.00	469.04	553.66
secondary crystalline granules, million, UAH	113.22	140.46	164.60	184.89	218.97
Revenue from electricity supply, million, UAH	145.89	165.35	176.75	180.98	195.44
Total revenue, million, UAH	740.67	967.37	1199.97	1438.06	1758.12

5 Conclusion

Sustainable development is a new worldview model of Ukraine's development, under which the transformation from a linear to a circular model of the economy has begun to balance the three interconnected components - economic growth, environmental protection and social protection of all members of the society. These items achievement key is adhering to the principles of sustainable development by regions, cities and territories, which today face one of the largest and most significant problems, which not only impedes their socio-economic development but also leads to the destruction of the environment – this is the problem of solid waste generation. The decision on this problem is to create an enabling environment for the successful implementation of eco-projects for MSW recycling of, and an effective tariff policy for MSW management services, which will not have a compensatory but stimulating character unlike the existing ones.

The correctness of the above statement is shown by the development of the nonlinear multi-factors economic-mathematical model of the relationship between tariffs and profitability of eco-project for the construction of MSW recycling plant in the Poltava sub-region using correlation-regression analysis. The validity of the proposed model is proved. Thus, the model makes possible to clearly determine the dependence of the expected eco-project revenue from the change in tariffs for MSW management services for each of the consumer categories. However, we recommend introducing a single tariff without subdivision of consumers into categories, which will ensure transparency of the tariff policy. According to the results of the study, it was allowed establishing deficiencies and rigidities in tariffs and services of MSW. The model helps to identify proposals for its effectiveness strengthen in ensuring compliance with the principles of sustainable development of the economy not only of regions but also of the whole country, and to outline vectors creation of eco-cities in Ukraine.

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Holistic approach based assessment of social efficiency of research conducted by higher educational establishments

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Abstract. Social efficiency of research conducted by higher educational establishments contributes a lot to improving the educational process, the quality of training of specialists, and the teaching skills of scientific and pedagogical staff. A holistic approach in the system of assessment of the social efficiency of higher educational establishments' research, which is interpreted by the authors of the article, makes it possible for higher educational establishments to completely adapt to market requirements, to make adequate managerial decisions and obtain relevant results. The system and structural approach was used in the study, which led to functional and effective application of theoretical provisions, scientific principles and conceptual positions for developing the author's version of forming higher educational establishments' holistic approach based model of social efficiency of research. For the assessment of social efficiency of research, a holistic approach based theoretical and analytical model has been suggested, which integrates 4 subsystems: target, provision, regulatory, management subsystem, which can be assessed by parameters, indicators and criteria of social efficiency of research results. The authors have suggested a system of criteria of social efficiency of research results. On the basis of the elaborated system of criteria assessment of social efficiency of research results of higher educational establishments, the authors have constructed a structural and logical scheme of social efficiency of research results assessment, which shows that on each stage of social efficiency of research results development by means of comparison of the market needs and opportunities of higher educational establishments and rational distribution of endowment funds it is possible to achieve maximization of the social efficiency of research results generalized criterion value. A formal description of the main components of the constructed theoretical-analytical model of the social efficiency of research has been made by means of using the economic and mathematical model and the dependence of its components has been analyzed.

1 Introduction

The specific nature of higher education, the versatility and multidimensionality of forms of work place particular demands on the assessment of the efficiency of both its activities as a whole and of academic research work (ARW). The issue is complicated by the need to determine not only the economic efficiency of the ARW conducted by higher educational establishment (HEE), but also social efficiency, that is, its impact on the educational process, improving the quality of training specialists, increasing the teaching skills of academic staff, etc.

Social efficiency of ARW in higher education emerges in:
- the development of the potential of higher education by means of the implementation of innovative technologies in the process of training professionals;
- the preservation and production of scientific potential of the higher educational establishment;
- the creation of new curricula, training courses which are relevant to the public needs and introduction of new forms of learning based on the results of ARW;
- dissemination of results of ARW in other higher educational establishments in Ukraine and abroad;
- participation in scientific projects, grant programs, including international ones, etc.

HEEs and scientific research are an integral part of a single whole, provided that this educational establishment strives to make progress and stand out from others by its innovational activity, desire to improve, promote, simplify and enhance any processes in science, economy, production in other spheres of

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human life [1].

The HEEs of the 21st century increasingly recognize the need for a comprehensive approach that goes beyond traditional management principles. The new approach, which allows to most completely adapt HEEs to today's market requirements, is a holistic one, which is to provide a comprehensive approach in the system of assessment of the ARW efficiency in order to make adequate management decisions and obtain appropriate results.

Holism (from Greek "holos" – all, whole, entire) is a methodological principle and a worldview concept that affirms the integrity and indivisibility of the material and spiritual world [2].

In a broad sense it is a principle of philosophy and science, which consists in admitting qualitative originality and priority of the whole in relation to its parts; in a narrow sense holism implies "philosophy of integrity" developed by the South African philosopher Jan Smuts, who introduced the term "holism" in 1926, based on Aristotle's claim that "the whole is greater than a sum of its parts" [3]. Smuts regards integrity as the highest philosophical category that synthesizes the subjective and objective and is the final reality of existence. Holism is the process of evolution that gives rise to new objects as integral [2]. In gnoseology, holism is based on the following principle: the knowledge of the whole must precede the knowledge of its parts. Many philosophers adhered to this principle. So, Hegel wrote, "... only the whole makes sense". In the 17th-19th centuries, in the course of scientific advancement, scientists began to consider any system as derived from parts, and believed that the properties of any object can be deduced from the analysis of its elements" [3].

It should be pointed out that holistic ideas have been long known in the West. J. W. Goethe is considered to be the first Western preacher of holistic thinking. He developed his own scientific method Anschauung ("Sense perception"). Another milestone in the history of the holistic paradigm is represented by the works of the German psychologist Max Wertheimer. In early 20th century, he conducted experiments proving that human perception of the environment is holistic, unified and it is supported by logics only after the specification of each individual part of the whole.

Such sciences as cybernetics, catastrophe theory, and complexity science have emerged on the basis of the above-mentioned theories and continue their development. So, complexity science is the source of many new applied fields, including social science [4].

The vitality of the research in this area is based on the fact that in domestic and foreign literature theoretical and methodological basis of the use of the holistic approach for assessing social efficiency of HEEs' scientific research is absent in fact, which does not allow to use its potential to the full.

2 Research problem and questions

The problem of the assessment of efficiency of scientific activity of HEEs has been in the focus of attention of such domestic and foreign scientists as A. M. Bondar [5], Yu. G. Bondarenko, S. M. Vyshniovska [1], A. A. Borisov [6], S. Gralka, K. Wohlrabe, L. Bornmann [7], V. A. Karpov, T. S. Koroliova, A. Z. Pidgornyi [8], V. M. Sinchenko [9], Ch. Tse Kuah, K. Yew Wong [10], T. G. Valderrama, T. L. C. M. Groot [11], D. Visbal-Cadavid, M. Martínez-Gómez, F. Guijarro [12], I. Ye. Zhurba [13], R.-L. Shi, N. He, Y. Liu [14], A. Jain, R. Sharma, P. V. Ilavarasan [15], G. Lebedev, O. Krylov, A. Lelyakov, Y. Mironov, V. Tkachenko, S. Zykov [16], X. Xiong, G.-L. Yang, Zh.-Ch. Guan [17], E. V. Romanov [18]. They defined the criteria and methodology of assessment of the efficiency of HEEs' research and paid great attention to studying their economic efficiency, however, they did not study their social efficiency sufficiently enough. Apart from that, the holistic approach, its theoretical understanding as the most progressive approach to the assessment of social efficiency of research (SER) in the process of forming the market of social orientation, in which the domestic HEEs function, are hardly presented in the scientific works of Ukrainian and foreign scientists and practitioners.

The purpose of this study is to solve the scientific problem of forming methodology of the assessment of SER based on the use of the potential of a holistic approach in the system of HEEs management in market conditions.

The research is based on a systemic-structural approach, which allows using theoretical provisions, scientific principles and conceptual positions functionally and effectively for developing the author's version of the formation of the model of SER of HEEs based on a holistic approach.

3 Findings of the research

The problem of determining socio-economic efficiency of scientific and technological research is developed as a problem of making difficult socio-economic decisions. The social results of the implementation of ARW that were conducted in HEEs are considered as additional indicators of their significance and were taken into consideration in approving the decision on the implementation of this scientific direction and on condition of the state support, can be used as information for the HEEs' accreditation. The social effect in the field of higher education appears primarily in the process of transferring new scientific knowledge and new technologies to HEE students. The social efficiency of ARW is assessed in the following areas: participation in the development of new technologies in educational sphere; participation in educational and teaching processes; conservation and development of scientific potential. The immediate component of the level of social effect is the development of new technologies in education. The objective indicators of this direction of ARW social efficiency are as follows: the number of training courses, which are based on the ideas of development; the availability of new forms of learning, as a result of the ARW results' implementation; the

number of HEEs that use the results of research and development in the educational process. The objective indicators of the impact of the ARW results on the educational and learning process are: the number of lectures and practical classes where the ARW results are used; the amount of published literature on education and methodology, which is based on the results of research and development; the number of students familiarized with the results of research and development (participation in lectures, practical classes, seminars and other forms of study). The objective indicators of the impact of ARW on the preservation and development of scientific potential are: the quota of doctors of sciences and doctoral students participating in ARW in the total number; the quota of candidates of sciences participating in ARW in the total number; the quota of students participating in ARW in the total number; the quota of students participating in ARW in the total number [8].

We consider it necessary to prolong the list of objective indicators of the impact of ARW results on the educational and teaching/learning process with the number of lab classes, trainings, international internships, the number of the carried out projects (including those conducted with the grant support), the number of students participating in international mobility programs. In order to align the scientific titles to the international standards, the Candidate of Economic Sciences is proposed to be replaced by PhD.

For the purpose of unifying, the terms employed in the given article "academic research work ", "research and development work", "scientific and technological work" used in national normative documents and scientific works, are suggested to be replaced by "research".

The world practice shows that the idea of a holistic approach extends to management processes, structural actions in an organization, economic efficiency, and corporate identity. Therefore, we suggest using a holistic approach in the assessment of SER, which allows for a coherent approach to the study of this issue. Owing to a holistic approach, integrity is achieved both in theory and in practice. The efficiency of research can be provided only by means of integrated data, bringing them together into a single management system and analyzing them in the course of time in accordance with the set goals and with reference to all the factors of influence. The efficiency of research can be achieved only if it is considered from the point of view of systemic integrity, which involves the integration and analysis of data obtained from different sources.

It is the holistic approach to the assessment of HEEs' SER that makes it possible to fully use the existing types of assessment and to form a development strategy of HEEs' researches in order to improve their social efficiency.

The theoretical and analytical model of SER is constructed on the basis of the holistic approach (XYZ-models), which is described by the following subsystems: "X" – target subsystem, "Y" – subsystem of provision, "XY" – regulatory subsystem, "Z" – management subsystem, which can be assessed by the parameters, indicators, criteria of social efficiency of research results (SERR) (Fig. 1) [19].

The target subsystem "X" (development of social efficiency) demonstrates the management cycle (set of stages, processes, functions that should be performed in order to achieve the goal (obtaining the results) [19]. The set of processes, which need to be implemented for forming of social efficiency, is determined by the factors of reaching goals, which are divided into macro- and micro-levels ("Y" subsystem).

The macro-level factors affecting SERR comprise:

Y_{macro1} – influence on the development of fundamental science, the most important applied research and development;

Y_{macro2} – increase in the efficiency of regulating science and technology development by the state;

Y_{macro3} – influence on improvement of national innovation system;

Y_{macro4} – increase in the efficiency of using the results of scientific and scientific-technological activities;

Y_{macro5} – influence on development of human resources potential of domestic scientific and technological complex;

Y_{macro6} – influence on the growth of integration of science and education;

Y_{macro7} – ensuring the development of international scientific and technological cooperation;

Y_{macro8} – emergence of additional social services;

Y_{macro9} – change of consumer price index;

$Y_{macro10}$ – increase in the provision of housing;

$Y_{macro11}$ – decline in unemployment, increase in birth rate and reduction of death rate;

$Y_{macro12}$ – the impact of innovative activities on the environment (decreasing acoustic noise level, soil and air pollution, mitigation of the electromagnetic field effect, mechanical vibrations, etc.).

The micro- level factors affecting SERR comprise:

Y_{micro1} – the human resources standard and growth;

Y_{micro2} – the number of patents and other copyrights, based on the results of prospecting, research and development work;

Y_{micro3} – the volume and economic efficiency of contracts on selling intellectual property rights (the number of agreements, the speed of diffusion of innovations, etc.);

Y_{micro4} – the volume and economic efficiency of unique equipment usage services;

Y_{micro5} – the efficiency of the transformation of knowledge, skills, ideas and habits acquired in the process of learning;

Y_{micro6} – the efficiency of transformation of scientific knowledge into innovations (products, production technologies, etc.);

Y_{micro7} – the volume and economic efficiency of consulting services;

Y_{micro8} – the level of integration of education, science and production, which reflects the synergistic effect of research;

Y_{micro9} – the efficiency of use of the endowment (level and rate of growth of financial independence, the volume of raised investments, income from the use of the fund).

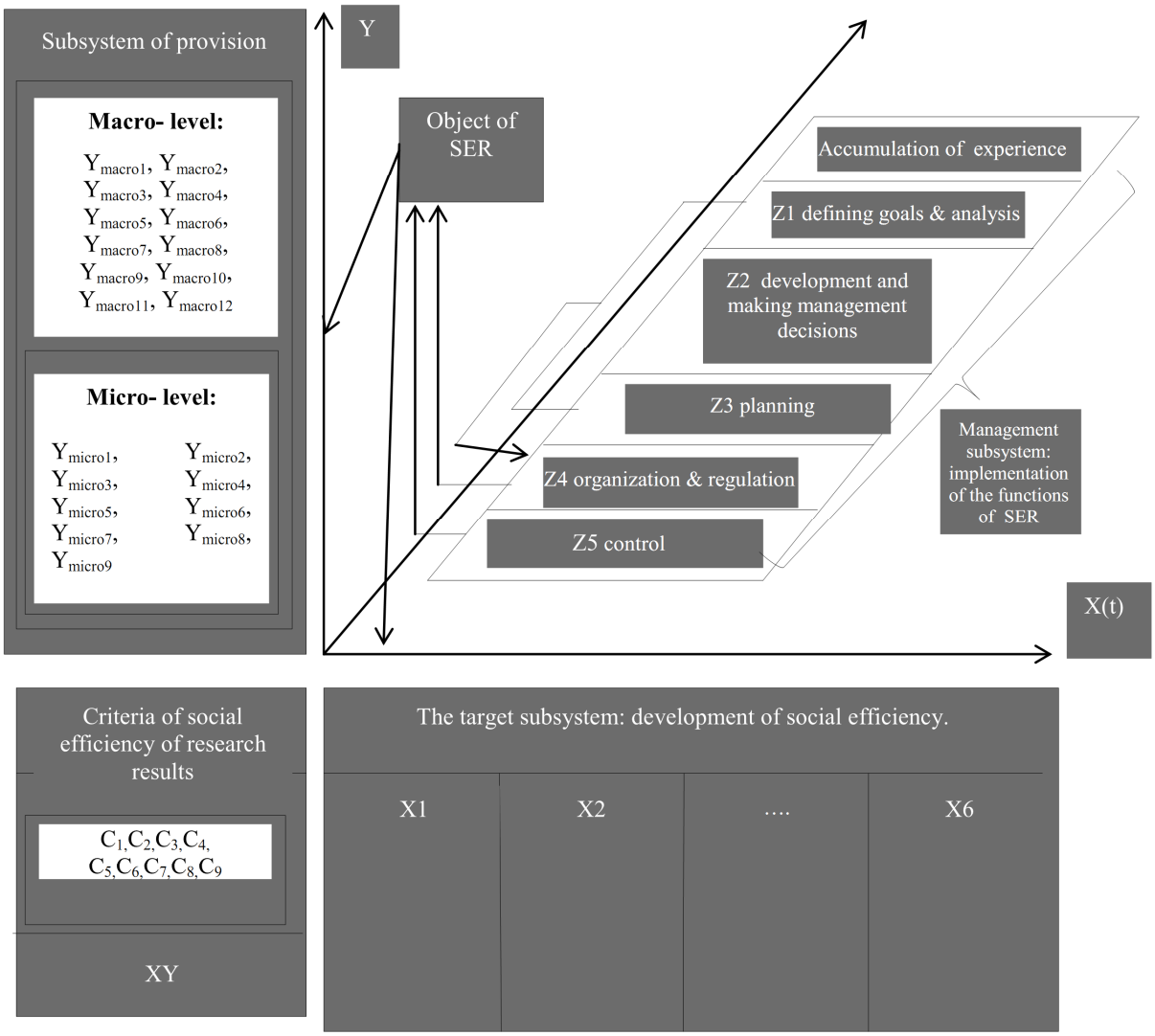

Fig. 1. Theoretical and analytical model of SER.

The management subsystem ("Z") reflects the implementation of the general management functions of the SER on the background of accumulated experience and is aimed at achieving results. Such a system of relations requires the improvement and stabilization of the system of laws, by-laws, instructions, orders, that is, the entire regulatory framework (subsystem "XY").

We suggest the SERR criteria system, which is a combination of static and dynamic microeconomic indicators of the species:

$$C_j = \sqrt[n_j]{\prod_{i=1}^{n_j} C_{ji}^{W_{ji}}}, \qquad (1)$$

where C_j is the criterion of social efficiency of the results of the j-th direction of scientific research; C_{ji} is the criterion of social efficiency of the results of the i-th component of the j-th direction of scientific research; n_j is the number of evaluated components of social efficiency of the j-th direction of scientific research; w_{ij} is the weightage of the i-th component of the j-th direction of scientific research.

The SERR criteria, which are determined with reference to the data for the reporting period compared to the baseline, are presented below.

The criterion of the assessment of human resources:

$$C_1 = \sqrt[2]{\left(\frac{L_{hr}}{L_{hrb}}\right)^{w_{11}} \left(\frac{L_{hr(r)}}{L_{hrb(b)}}\right)^{w_{12}}}, \qquad (2)$$

where L_{hr} is the level of human resources of research and development works; L_{hrb} – the level of human resources of the establishment selected as a comparison base; b, r – base and reporting period of assessment; w_{11}, w_{12} – weight coefficients of static and dynamic assessments of human resources ($w_{11} + w_{12}$) = 2.

The criterion of assessment of the social efficiency of creating copyright objects by the results of prospecting, research and development works:

$$C_2 = \sqrt[3]{\left(\frac{N_{co}}{N_{cob}}\right)^{w_{21}} \left(\frac{MV_{co}}{C_{co}}\right)^{w_{22}} \left(\frac{N_{co(r)}}{N_{cob(b)}}\right)^{w_{23}}}, \qquad (3)$$

where N_{co} is the number of copyright objects; N_{cob} is the number of copyright objects created by the establishment selected as a comparison base; MV_{co} – the market value of copyright objects; C_{co} – the cost of creating copyright

objects; w_{21}, w_{22}, w_{23} are the weight coefficients of the relevant criteria of social efficiency of creating copyright objects ($w_{11} + w_{12} + w_{23}$) = 3.

Criteria of the efficiency of contracts on selling intellectual property objects:

$$C_3 = \sqrt[4]{\left(\frac{V_{cipo}}{V_{cipob}}\right)^{w_{31}} \left(\frac{AV_{ipo}}{C_{ipo}}\right)^{w_{32}} \left(\frac{V_{cipo}(r)}{V_{cipob}(b)}\right)^{w_{33}} \left(\frac{S_{ipo}}{S_{ipob}}\right)^{w_{34}}} \quad (4)$$

where V_{cipo} is the volume of contracts on selling intellectual property objects; V_{cipob} – the volume of contracts on selling intellectual property objects created by the establishment selected as a comparison base; AV_{ipo} – the added value obtained from selling intellectual property objects; C_{ipo} – the cost of creating and promoting intellectual property objects; S_{ipo} – the speed of diffusion of intellectual property objects; S_{ipob} – the speed of diffusion of intellectual property objects created by the organization selected as a comparison base; w_{31}, w_{32}, w_{33}, w_{34} are the weight coefficients of the relevant criteria of the social efficiency of contracts on selling intellectual property rights ($w_{31} + w_{32} + w_{33} + w_{34} = 4$).

The criterion of the social efficiency of unique equipment usage services provided by HEE:

$$C_4 = \sqrt[3]{\left(\frac{V_{ueus}}{V_{ueusb}}\right)^{w_{41}} \left(\frac{R_{ueus}}{C_{ueus}}\right)^{w_{42}} \left(\frac{V_{ueus}(r)}{V_{ueusb}(b)}\right)^{w_{43}}}, \quad (5)$$

where V_{ueus} is the volume of unique equipment usage services provided by HEE; V_{ueusb} – the volume of unique equipment usage services provided by the establishment selected as a comparison base; R_{ueus} – revenue from the unique equipment usage services; C_{ueus} – the cost of unique equipment usage services; w_{41}, w_{42}, w_{43}, are the weight coefficients of the relevant criteria of social efficiency of unique equipment usage services ($w_{41}+w_{42}+w_{43} = 3$).

The criterion of social efficiency of the transformation of knowledge, ideas, skills and abilities acquired in the learning process:

$$C_5 = \sqrt[2]{\left(\frac{Q_s}{Q_{sb}}\right)^{w_{51}} \left(\frac{Q_s(r)}{Q_{sb}(b)}\right)^{w_{52}}}, \quad (6)$$

where Q_s is the quota of specialists who have obtained a scientific degree in the total number of the graduate students; Q_{sb} is the quota of specialists who have obtained a scientific degree in the total number of the graduate students in the establishment selected as a comparison base; w_{51}, w_{52} are the weight coefficients of static and dynamic assessments of the quota of specialists who have obtained a scientific degree in the total number of the graduate students ($w_{51} + w_{52} = 2$).

The criterion of social efficiency of innovating scientific knowledge:

$$C_6 = \sqrt[4]{\left(\frac{AV_{ipo}}{MV_{co}}\right)^{w_{61}} \left(\frac{\left(\frac{AV_{ipo}}{MV_{co}}\right)(r)}{\left(\frac{AV_{ipob}}{MV_{cob}}\right)(b)}\right)^{w_{62}} \left(\frac{AV_{ipo}}{C_{ipo}}\right)^{w_{63}} \left(\frac{P(r)}{P(b)}\right)^{w_{64}}} \quad (7)$$

where P is the period of innovating scientific knowledge; AV_{ipob} – added value obtained in the implementation of intellectual property objects in the establishment selected as a comparison base; MV_{cob} – the market value of copyright objects in the establishment selected as a comparison base; w_{61}, w_{62}, w_{63}, w_{64} are the weight coefficients of the relevant criteria of social efficiency of innovating scientific knowledge ($w_{61}+w_{62}+w_{63}+w_{64} = 4$).

The criterion of consulting services efficiency:

$$C_7 = \sqrt[3]{\left(\frac{V_{cs}}{V_{csb}}\right)^{w_{71}} \left(\frac{R_{cs}}{C_{cs}}\right)^{w_{72}} \left(\frac{V_{cs}(r)}{V_{csb}(b)}\right)^{w_{73}}}, \quad (8)$$

where V_{cs} – amount of consulting services; V_{csb} – amount of consulting services provided by the establishment selected as a comparison base; R_{cs} – revenues from providing consulting services; C_{cs} – cost of consulting services; w_{71}, w_{72}, w_{73} are the weight coefficients of the relevant criteria of consulting services social efficiency ($w_{71}+w_{72}+w_{73} = 3$).

The criterion of social efficiency of education, science and production integration:

$$C_8 = \left[\left(\frac{R_{es}}{R_{esb}}\right)^{w_{81}} \left(\frac{V_{or}}{V_{orb}}\right)^{w_{82}} \left(\frac{V_{rii}}{V_{riib}}\right)^{w_{83}} \times \right.$$

$$\left. \times \left(\frac{R_{es}(r)}{R_{esb}(b)}\right)^{w_{84}} \left(\frac{V_{or}(r)}{V_{orb}(b)}\right)^{w_{85}} \left(\frac{V_{rii}(r)}{V_{riib}(b)}\right)^{w_{86}}\right]^{\frac{1}{6}}, \quad (9)$$

where R_{es}, R_{esb} is the ratio of educational services provided by the establishment and organization selected as a comparison base, respectively; V_{or}, V_{orb} – the volume of orders for researches per specialist received by the establishment and organization selected as a comparison base, respectively; V_{rii}, V_{riib} – the volume of realization of industrial innovations per specialist by the establishment and organization selected as a comparison base, respectively; w_{81}, w_{82}, w_{83}, w_{84}, w_{85}, w_{86} are the weight coefficients of the relevant criteria of social efficiency of education, science and production integration ($w_{81}+w_{82}+w_{83}+w_{84}+w_{85}+w_{86} = 6$).

The criterion of social efficiency of the use of the endowment (target capital fund):

$$C_9 = \sqrt[6]{\left(\frac{L_{fi}}{L_{fib}}\right)^{w_{91}} \left(\frac{A_{li}}{A_{lib}}\right)^{w_{92}} \left(\frac{P_{ia}}{P_{iab}}\right)^{w_{93}}} \times$$

$$\times \sqrt[6]{\left(\frac{L_{fi}(r)}{L_{fib}(b)}\right)^{w_{94}} \left(\frac{A_{li}(r)}{A_{lib}(b)}\right)^{w_{95}} \left(\frac{P_{ia}(r)}{P_{iab}(b)}\right)^{w_{96}}}, \quad (10)$$

where L_{fi}, L_{fib} is the level of financial independence evaluated by the establishment and organization selected as a comparison base, respectively; A_{li}, A_{lib} – the amount of long-term investments involved by the institution and organization selected as a comparison base, respectively; P_{ia}, P_{iab} – the profitability of innovation activity of the establishment and organization selected as a comparison base, respectively; w_{91}, w_{92}, w_{93}, w_{94}, w_{95}, w_{96} are the weight coefficients of the relevant criteria of social efficiency of the use of the endowment ($w_{91}+w_{92}+w_{93}+w_{94}+w_{95}+w_{96} = 6$).

Following the developed system of SERR criteria, it is possible to form a generalized criterion of SERR:

$$C_{SERR} = \sum_j C_j \times \beta_j, \quad (11)$$

where β_j – is the weight of SERR criteria which are determined by the condition

$$\sum_j \beta_j = 1, \quad (12)$$

The weight is determined on the basis of the expert judgment of the decision-maker, in accordance with the weight of a particular type of research carried out by a HEE.

The X axis is the target subsystem: the process of social efficiency development. This subsystem is represented by the following constituent processes: X1 – assessment of market demands for human resources, educational services, intellectual property objects, unique equipment usage services, scientific knowledge; innovations, consulting services, X2 – identification of the potential of increase in SERR by criteria, X3 – ranking of increase in SERR by criteria, X4 – allocation of resources of the endowment in proportion to the increase in SERR by criteria, X5 – assessing the increase in social efficiency of integration of education, science and production by a higher educational establishment (K8), X6 – assessment of increase in SERR.

On the basis of the developed system of assessment criteria of innovation activity efficiency of a higher educational establishment, a structural and logical scheme of SERR assessment has been formed (Fig. 2).

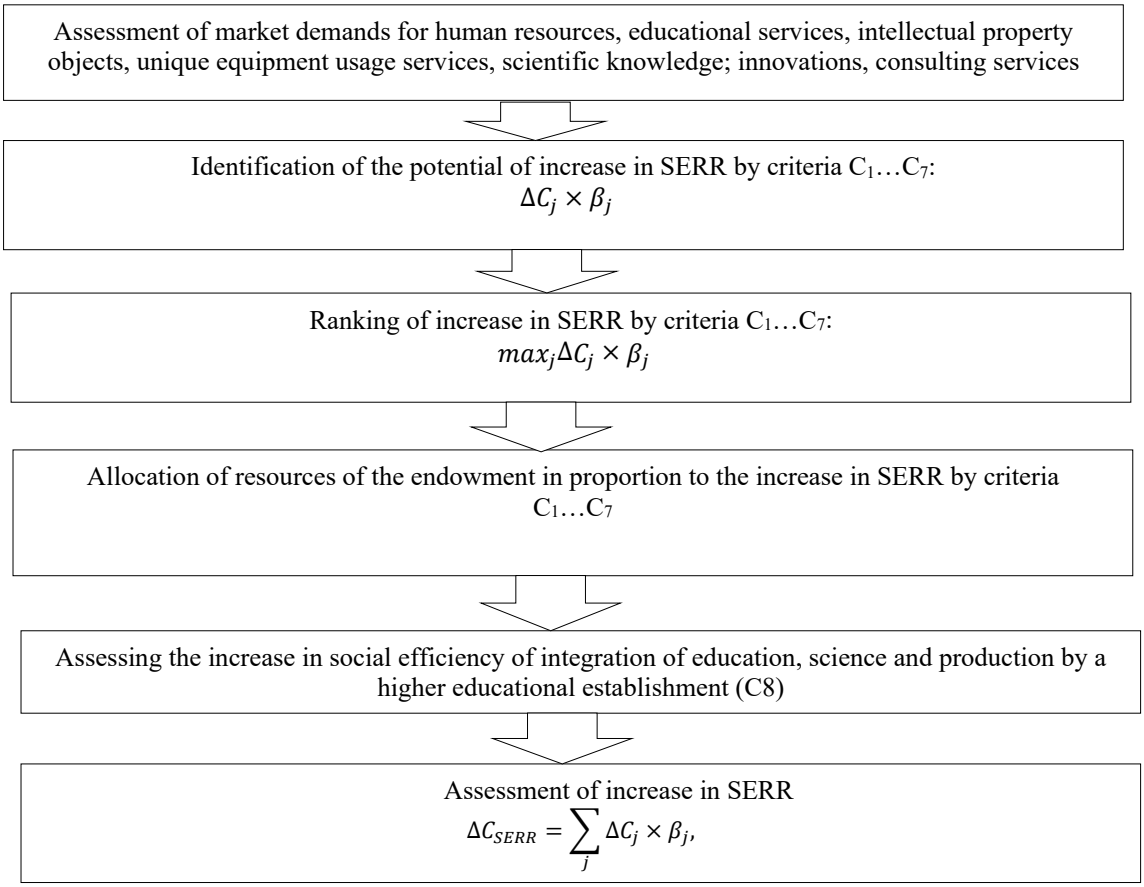

Fig. 2. Sequence of SERR development stages (developed on the basis of [6]).

Thus, at each stage of SERR development, it is possible to achieve maximization of the value of generalized social efficiency criterion of SERR by comparing market demands and opportunities of a HEE by means of the rational allocation of endowment.

The management subsystem (Z-axis) shows the implementation of SER general functions. We specify them: Z1 – defining goals and SER analysis, Z2 – development and making management decisions, Z3 – planning SER, Z4 – organization and regulation of SER, Z5 – control as a SER tool.

To assess SER, a theoretical and analytical model has been suggested. It is based on a systematic approach that integrates the subsystems described above, which can be analyzed by quantitative and qualitative methods. Mathematical modeling was applied for describing the theoretical and analytical model [20]. It made it possible to obtain a simplified, abstract, formally described model. The latter covers a class of undetermined parameters or vectors, interaction and relations between them that can be described by mathematical operations. The influence of mathematical modeling on economic theory is variegated. Presenting many economic problems in a formalized language makes it possible to avert ambiguity of thinking, clarifies the essence of the problem to a great degree, and vividly demonstrates

doctrines. In addition, the use of mathematical language helps to specify many economic concepts, systematize theoretical knowledge better, and enrich the conceptual apparatus of economics [21]. The main components of the developed SER theoretical and analytical model has been formally described with the help of the economic-mathematical model and the relationships between its components have been analyzed. The first function of "Setting goals and SER analysis" concerns the component of assessment of market demands in human resources, educational services, objects of intellectual property, unique equipment usage services, scientific knowledge, innovations, consulting services. In the course of SER analysis, the function in question will be influenced by the factors at the macro level. A graphical description of the foresaid is shown in Fig. 3.

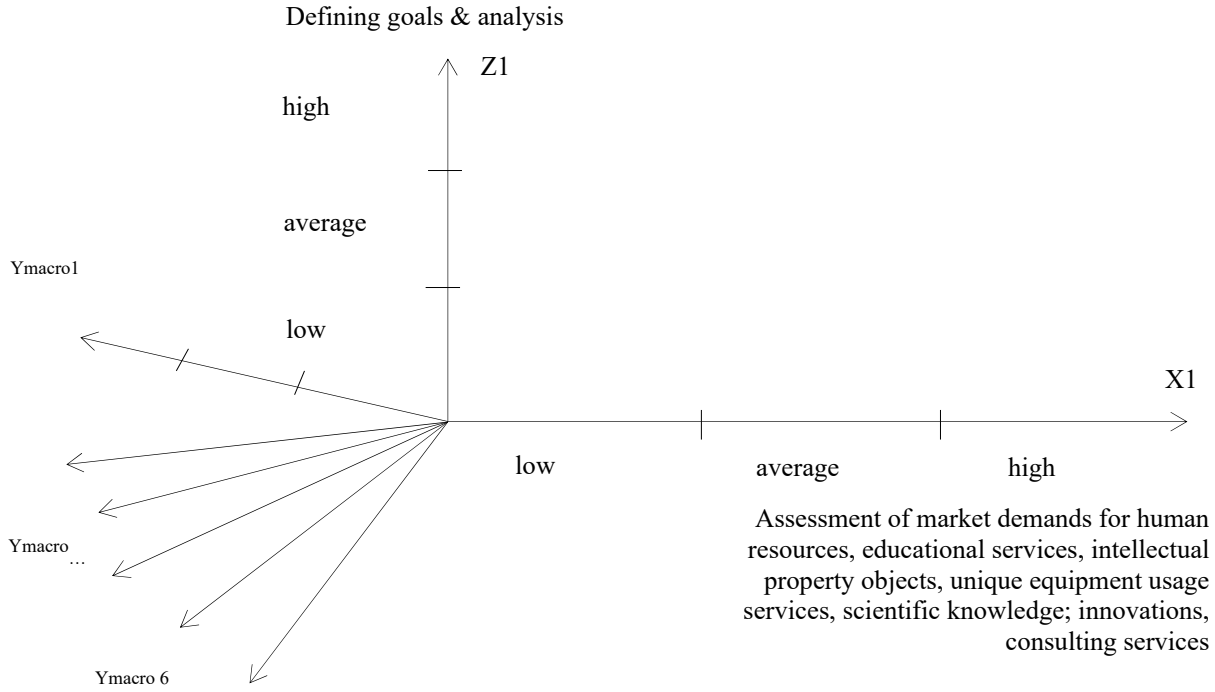

Fig. 3. The degree of dependence of defining goals and SER analysis on the assessment of market demands in human resources, educational services, objects of intellectual property, unique equipment usage services, scientific knowledge, innovations, consulting services in view of micro level factors.

With reference to this aspect, goals are specified in accordance with micro level factors if the goals diverge from the general trend during natural disasters, military events etc. It is up to the researchers to choose the assessment scales taking into consideration the need for detail (for example, from 0 to 1 incrementally).

Graphical description allows to make mathematical dependence of management analysis and goal setting on the assessment of market needs for human resources, educational services, objects of intellectual property, unique equipment usage services, scientific knowledge, innovations, consulting services.

$$Z_1 = a_1 \times X_1 + b_{1.1} \times Y_{macro1.1} + b_{1.2} \times Y_{macro1.2} + b_{1.3} \times Y_{macro1.3} + b_{1.4} \times Y_{macro1.4} + b_{1.5} \times Y_{macro1.5} + b_{1.6} \times Y_{macro1.6} + const$$

where *a* and *b* are regression coefficients showing the degree of influence of each factor on the function; *X*, *Y* are factors that are independent variables that influence the function; *const* are factors that do not affect the result but are present in the model.

Similarly, we analyze the following relationships and combine the obtained equations into a system of equations [22]:

$$\begin{cases} Z_1 = a_1 \times X_1 + b_{1.1} \times Y_{macro1.1} + \\ + b_{1.2} \times Y_{macro1.2} + b_{1.3} \times Y_{macro1.3} + \\ + b_{1.4} \times Y_{macro1.4} + b_{1.5} \times Y_{macro1.5} + \\ + b_{1.6} \times Y_{macro1.6} + const \\ Z_2 = a_2 \times X_3 + b_{2.1} \times Y_{macro2.1} + \\ + b_{2.2} \times Y_{macro2.2} + \\ + b_{2.3} \times Y_{macro2.3} + b_{2.4} \times Y_{macro2.4} + \\ + b_{2.5} \times Y_{macro2.5} + b_{2.6} \times Y_{macro2.6} + \\ + b_{2.7} \times Y_{micro2.1} + b_{2.8} \times Y_{micro2.2} + \\ + b_{2.9} \times Y_{micro2.3} + const \\ Z_3 = a_3 \times X_2 + b_{3.1} \times Y_{micro3.1} + \\ + b_{3.2} \times Y_{micro3.2} + b_{3.3} \times Y_{micro3.3} + const \\ Z_4 = a_4 \times X_2 + b_{4.1} \times Y_{macro4.1} + \\ + b_{4.2} \times Y_{micro4.2} + \\ + b_{4.3} \times Y_{macro4.3} + b_{4.4} \times Y_{macro4.4} + \\ + b_{4.5} \times Y_{macro4.5} + b_{4.6} \times Y_{macro4.6} + const \\ Z_5 = a_5 \times X_4 + b_{5.1} \times Y_{micro5.1} + \\ + b_{5.2} \times Y_{micro5.2} + b_{5.3} \times Y_{micro5.3} + const \end{cases}$$

It is relevant to use a linear multiple regression program for solving the system of equations. To demonstrate the abovementioned methodology, the results of 3 research issues of Ivano-Frankivsk National

Technical University of Oil and Gas are taken as an experiment. The expert method was used in the research, which was conducted in 3 stages: experiment 1 (Z), experiment 2 (Z′) and experiment 3 (Z″) (Table 1). To reduce oscillations and offset the error of the results of the experiment, the experts chose the aggregated scale as an example.

Table 1. Calculation of the SER level.

No	Standard	SER level			Standard correspondence (+/-)			Weight coefficient assignment			Adjusted SER level value		
		Z	Z′	Z″	Z	Z′	Z″	Z	Z′	Z″	Z	Z′	Z″
1	1	1	1	2	+	+	-	0,35	0,6	0,1	0,35	0,6	0,2
2	2	2	3	3	+	-	-	0,35	0,1	0,1	0,7	0,3	0,3
3	2	1	1	2	-	-	+	0,1	0,1	0,6	0,1	0,1	1,2
4	1	2	2	2	-	-	-	0,1	0,1	0,1	0,2	0,2	0,2
5	2	1	1	1	-	-	-	0,1	0,1	0,1	0,1	0,1	0,1
Total Value	6	7	8	10	X	X	X	1	1	1	1,45	1,3	2

Based on table 1, the obtained results were analyzed according to the accepted levels: 0-1,2 – low; 1.21-2.4 – average; 2.41-3 – high. Also, the dynamics (growth / decline) of the obtained results were determined (Table 2).

Table 2. Defining the SER level and its dynamics.

Stage	Value	Comparison between real value and accepted levels	SER level	Absolute divergence	Relative divergence
Z	1,45	1,21 – 2,4	average	-	-
Z′	1,3	1,21 – 2,4	average	-0,15	-0,11
Z″	2	1,21 – 2,4	average	+0,7	+0,54

Thus, with reference to the obtained results, the SER average level has been diagnosed. However, in determining the absolute and relative divergences, we have observed both positive and negative dynamics within one level. While during the first experiment the average SER level (1,45) was found, during the second experiment, the SER level decreased by 11%, although it kept staying at the average level. But long re-diagnosis showed an increase of the SER level by 54%.

4 Conclusions

The main competitive advantages of HEE research result from managing innovations. A holistic approach allowed us to construct the integrated model that takes into consideration the possibility of achieving one of the components of the overall research goal – achieving social effect. The constituent models of assessment are complementary and contribute to obtaining complete and comprehensive information related to SER.

The conceptual model based on a holistic approach, is focused on satisfying the interests of specific HEEs and users of research results, on increasing the competitiveness of research results, development of resource and investment capabilities of HEEs as a whole, and, consequently, on improving the standard of life of society by enhancing social trends in the management of scientific research.

The holistic approach to the assessment of SER interpreted by the authors of the article contains 4 subsystems: subsystem of provision, regulatory subsystem, management subsystem, which are described by means of the theoretical and analytical model of SER. The article comes up with an innovative model of SER assessment. An instrument of mathematical modeling has been used to interpret this model, which made it possible to analyze the dependence of its components. The implementation of the model in HEEs will be a viable tool for the demonstration of SER assessment.

Moreover, the model can be used by customers in assessing the significance of researches, in making decisions on giving grants and financing researches, in crediting enterprises and organizations on condition of feasibility of activities that are conducted according to investment projects and business contracts; in setting prices for scientific and technical products.

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Assessment model of regions' economy in the context of their sustainable development

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Abstract. Currently realizing the new active role of the region as a sustainable development entity is a strategic direction for regional policy's development. Assessing the sustainable development of regions is an important part of such a policy and facilitates the timely identification of internal and external threats, the development of the necessary stabilization measures to prevent their negative impact, and the formation of strategies aimed at the sustainable functioning of regional systems. The economic system is an important subsystem of the region. The article proposes an approach to assess the level of regions economic development in the context of ensuring its sustainable development. It is based on comprehensive assessment technology. The sustainable economic development composite index is calculated by a weighted additive convolution of partial indicators. A feature of the proposed approach is the simultaneous use of both metric and non-metric indicators. The metric component is used to calculate the composite index values. Weight coefficients are calculated by the principal component method using the factor loadings of the first principal component. The non-metric part of the initial data is used to refine these weights. The article describes the algorithm for calculating a composite index. The practical testing of the proposed approach is presented for the case Ukraine's regions. The results lead to the conclusion about significant problems in ensuring sustainable development of the regional economy. Outcomes obtained are very helpful for the public administration bodies to develop and revise the appropriate policy for solving the sustainable development problems in each region.

1 Introduction

Sustainable development is a modern worldview, political and practical model of development for all countries of the world, which have started the transition from a purely economic model of development to finding the optimal balance between the three components of development – economic, social and environmental. This category is perceived around the world as a model of civilized development. Implementation of this model requires the formation of a system for managing such development.

In September 2015, during the 70th session of the UN General Assembly in New York, the UN Summit on Sustainable Development took place and adopted the 2030 Agenda for Sustainable Development. It approved new development benchmarks [1]. Summit issues covered all aspects of socio-economic development, in particular, countries' competitiveness, environmental and energy security, global partnership for development, and were based on the principle of "Leaving no one behind". Summit Outcome Document contains 17 Sustainable Development Goals. This led to the update of the Sustainable Development Strategy of Ukraine until 2030 [2]. The Strategic vision of Sustainable Development of Ukraine is focused on overcoming the imbalances that exist in the economic, social, environmental spheres and is based on the vectors defined in the Sustainable Development Strategy "Ukraine 2020" [3], one of which is the vector of development. It foresees sustainable development of the country, carrying out structural reforms, ensuring economic growth in an environmentally sustainable way, creating favorable conditions for economic activity [2].

Thus, at the present stage of development of Ukraine's economy, the problem of transition to sustainable development of both the country as a whole and each of its regions is urgent. The balanced regions development should be oriented towards providing conditions that will allow each region of the country to have the needed and sufficient resources to ensure decent living conditions, comprehensive development and increase the competitiveness of the economy.

On the one hand, sustainable development of the region may be seen as a positively directed process of

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improving the economic, social and environmental components. On the other hand, it is considered as a process to achieve balanced state for all of these components.

The assessment of the level and state of sustainable development of regions' economy is necessary to identify internal and external threats, which will allow to devise measures to prevent their negative impact in order to identify scenarios of development and to develop an optimal strategy for the functioning of country's regional economic systems.

2 Literature review

The issue of assessing the level of sustainable development, both at the national and regional levels, remains a subject of many scholars' studies. Economic, social and environmental components have traditionally been taken into account for regional systems. In our study, the focus will be on assessing the economic component of regional development in the context of its sustainable development. We support the point of view of A. M. Zhuchenko [4, p. 432] that sustainability is understood as a property or quality that determines the ability of a regional system to be in a state of dynamic equilibrium in the presence of external and internal influences. Sustainability may be inherent not only in the fixed state of the regional system but also in its changes. As the main types of such stability can be distinguished as: the stability of development, characterized by a systematic increase in the result, which is not lower than the acceptable minimum and not higher than the objectively determined maximum; as permanent stability when changes, including positive ones, occur only occasionally and for a short time; as hyper-sustainability like a state where regions are not susceptible to development but are able to adapt to changes, including positive ones.

The analysis of publications [5-16] showed a variety of methodological approaches to assess sustainable development, which is determined by the identified goals to obtain evaluations. At the same time, most of the methodological approaches involve to calculate a composite (integrated, comprehensive) index of sustainable development based on the use of additive or multiplicative convolution. In some cases, the author's techniques involve the analysis of the output without the convolution, in particular, the indicative method of evaluation. In our view, narrowing the assessment outcome to a single indicator makes it easier to draw conclusions, but on the other hand, this approach causes a "compensation effect" when the low values of some indicators are offset by the high values of other ones. This disadvantage can be partially eliminated by using a weighted convolution of the initial indicators.

The paper [5] proposes a methodological approach to the assessment of sustainable development of Ukrainian regions, in which the overall assessment of its level is carried out using a composite index, based on the additive convolution of indicators of social, economic and environmental components. An integrated assessment of the sustainable development of the Ukraine's regions is carried out and problems of regions development in the social, economic and environmental fields are identified. It should be noted that the author proposes to use the financial statements, which, in our opinion, limits the application of the proposed methodology.

A. V. Horiana [6] distinguishes infrastructure and innovation components in addition to the traditional part of sustainable development to design a composite index. Author defines the rules of composite index calculation based on the multiplicative convolution and formulates the conditions under which sustainable development is reached. A similar approach is implemented in paper [7]. However, these approaches leave open the issues of identification the required set of initial data.

Study of O. Nesterenko [8] uses an approach based on the scoring model to assess the sustainable development composite index. At the same time, the author proposes to use both the statistical reporting indicators and questionnaires outcomes of evaluation of the several components of sustainable development. Commonly proposed method uses recognized indicators of human development like the Knowledge Index, the Human Capital Development Index, and the Human Development Index. It should be noted, that some of the used indicators have a non-numerical origin and therefore their mathematical processing is not always correct.

Papers [9, 10] proposed a set of criteria for assessing the sustainable development of a region based on the use of both metric and non-metric indicators. But authors do not specify the rules for processing data and constructing the resulting metric.

The experience of foreign scholars in solving the problems of sustainable development assessment is presented in [11-16]. In particular, paper [11] presents the author's methodology for assessing sustainable development for the Czech Republic according to four components: Political area, Social area, Economic area and Environmental area, which uses 101 output indicators and provides for the calculation of a hierarchical integral index system, which includes 12 partial indicators, 4 partial composite indicators and one aggregate integrated index of sustainable development.

Study [12] presents an original approach to the calculation of a comprehensive sustainable development index based on the case of Indonesia's regions. Authors propose three measures for indices: arithmetic, geometric and entropy-based. Indices are aggregated to use for comparing regions in terms of their stability. The article also analyzes the sensitivity of the results obtained. It should be noted that despite the ranking of regions by the value of the integrated indicator of sustainable development, the authors were not offered a scale to estimate the level of sustainable development of regions. An alternative approach to assess the sustainable development of Indonesia's regions is given in paper [13]. It is based on a combination of factor analysis and cluster analysis methods. First method is used to construct partial composite indices of sustainable development by each of its component, and the cluster analysis is used to group regions by the level of sustainable development. Authors propose to use the resulting cluster map of regencies and

municipalities to make a decision in order to identify appropriate policies to address problems in each region.

Studies [14-16] have presented approaches for assessing the degree of achievement of the 17 Sustainable Development Goals identified in [1] in a case of Asian countries.

The conducted analysis of publications makes it possible to conclude that the presented approaches are based on the UN Sustainable Development Concept using some differences in the structure of components and the number of partial indicators. Advantages of the composite indexes for evaluation of various aspects of sustainable development include the simplicity of their calculation and the ease of results interpretation. However, the approaches don't contain criteria for identifying the level of sustainable development. A significant disadvantage of these methods is the use of an overloaded set of partial indicators, which, moreover, don't always correspond to the system of national statistics. Tis fact creates a multiplier effect and complicates the assessment in dynamics. There is also a methodological problem to select indicators to be included to the index and with the identification of weights of partial indicators.

The results of this review cause to develop our own approach to assess the region economy in the context of its sustainable development.

3 Problem description and methodology

To assess the economic development of the regions, we propose an approach based on the calculation of the composite index. An important step in its design is the shaping of an information base that includes a set of initial partial indicators that characterize sustainable development. It should be noted that an excessive number of initial partial indicators reduces ability of composite index to account of the variability of the components. In addition, the use of a weighted convolution may either lead to the elimination of differences between their importance or to the loss of statistical significance of some of them. Also, we note, that some of the initial data may have a non-numerical origin, which causes to take into account the non-metric indicators in calculations.

We propose an approach to design an integral metric to assess the regions' economic development by considering both metric and non-metric indicators. In this case, the metric part of the set of partial indicators will be used to calculate the numerical values of the composite index, and the non-metric component of this set will be used to specify the weighting coefficients of metric indicators in their convolution. The construction of a composite index is carried out by using a weighted convolution of the initial metric indicators. We use the principal components method to calculate their primary weights in order to take into account in convolution. Calculation of the weight coefficients values is made in proportion to the factor loadings of the initial indices of the first principal component. The final values of weight coefficients are executed with taking into account the correlation coefficients between numeric indicators and non-metric ones.

The designing procedure for composite index is implemented by the following algorithm.

1) Identifying set of partial indicators:

$$X = \{X^{(1)}|X^{(2)}\} = \{X_1^{(1)}, X_2^{(1)}, \ldots, X_{k1}^{(1)}, X_1^{(2)}, X_2^{(2)}, \ldots X_{k2}^{(2)}\}, \quad (1)$$

where $X^{(1)} = \{X_i^{(1)}\}$ is a subset of metric (nimerical) indicatots, i=1,2,…, k_1; $X^{(2)} = \{X_i^{(2)}\}$ – is a subset of non-metric indicatots, i=1,2,…, k_2; k_1, k_2 – appropriate numbers of indicators in each part of initial set, $k_1 + k_2 = n$;

n – common number of indicators.

We proposed to include indicators measured on a rank scale to the non-metric part of this set.

2) Calculating correlation matrix R for metric subset initial data. To reach this aim, we propose to use Pearson's correlation coefficients.

3) Calculating the correlation coefficients values ρ_{ij} between metric $X_i^{(1)}$ and non-metric $X_j^{(2)}$ indicators, i=1,2,…, k_1; j=1,2,…, k_2. To reach this aim, we propose to use Spearman's rank correlation coefficients or Kendall's ones. In the case, when the construction of initial data non-metric part is carried out based on the expert evaluations, additionally we shoud assess the consistency of expert opinions by calculating the concordance coefficient. In the case of the dichotomous indicators (as a partial case of using rank scale), it is advisable to use a point-biserial correlation coefficient as a measure of interrelation between components of each part of initial data.

4) Normalization of metric indicators by reducing their values to a range from 0 to 1, with the formation of conformity of their increasing values to better quality. This procedure is necessary for the constructed composite index to be within [0; 1] and had a positive correlation with each of the initial components. In addition, the normalized values should be invariant to the units of measurement. Normalization can be done in different ways. The most common approach uses the conversion of initial data using the largest and / or smallest sample values [17]. The way of normalization depends on the origins of the initial indicators and their range of values. If the simple has a boundary or normative values limiting the growth of their positive quality, we may use the approach given in [18].

5) Designing a composite index using the following four-step procedure. The first step is to calculate the first principal component for a subset of metric indicators. It is known that it corresponds to the first (largest on absolute value) eigenvalue λ_1 of the correlation matrix R. In the second step, the factor loadings of the first principal component are calculated:

$$W = \{w_1, w_2, \ldots, w_{k1}\}. \quad (2)$$

In the case when the number of initial metric indicators is large enough, the use of all of them for the calculation of the composite indicator is impractical for the reasons stated above. It is recommended to select the most informative ones using the rule:

$$|w_i| \geq \delta, \quad (3)$$

where δ is a given level of factor loading significance; $i = 1, 2, \ldots, k_1$.

On the third step, we carry out the calculation of weight coefficients for metric initial indicators. These values are calculated taking into account the influence of non-metric indicators that were included to the appropriate part of initial set of data:

$$\alpha'_i = |w_i| \cdot \left|\prod_{j=1}^{k_1} \rho_{ij}\right|^{1/k_1} \quad (4)$$

where w_i is a factor loading of first principal component for i-th metric indicator of subset $X^{(1)}$, ρ_{ij} – value of the rank correlation coefficient between i-th metric component of subset $X^{(1)}$ and j-th non-metric component of subset $X^{(2)}$; $|z|$ – absolute value of z.

Since the obtained values of α'_j in total may differ from 1, we carry out their normalization:

$$\alpha_i = \frac{\alpha'_i}{\sum_{j=1}^{k_1} \alpha'_j}, \quad (5)$$

i=1, 2, …, k_1.

On the fourth step, we calculate a composite index using one of the ways for convolution of initial numeric indicators:

$$I = \sum_{i=1}^{k_1} \alpha_i U_i, \quad (6)$$

$$I = \prod_{i=1}^{k_1} U_i^{\alpha_i}, \quad (7)$$

$$I = -1 + \prod_{i=1}^{k_1} (1 + U_i)^{\alpha_i}, \quad (8)$$

where U_i – normalized values of metric indicators $X_i^{(1)}$, i=1, 2, …, k_1. Formula (6) present additive convolution, formulas (7) and (8) – multiplicative ones. It is also quite common to calculate the composite index using the distance method, but on our opinion, in this case its use is impractical, since this method involves the use of some "ideal" point, which is the standard of the studied quality. There is no sense of existence of such a point for considered problem.

4 Findings

Using the proposed approach to the design of a composite index, let we evaluate the economic development of the regions in the context of their sustainable development. As noted above, the sustainable development of a region may be seen as a process of improving the functioning all of its subsystems, including the economic one. For these reasons, we form a set of initial indicators. Obvious characteristics of development are relative indicators of dynamics, in particular, growth rates. However, we take into account, that usually such indicators have low variability within the country's economic system. So, in our view, it is more appropriate to use indicators of relative percentage increases.

Another problem that needs to be addressed in the formation of an information base for comprehensive assessment is the identification of the set of initial indicators. In our opinion, the subsystem of metric indicators should include those indicators that characterize the most important features of the regional economic system like GRP, industrial and agricultural production, investment and foreign economic activity.

Recently, it is quite common to use various rating evaluations, which reflect the level of regional development. They are calculated on the basis of the main indicators of the functioning of all regional subsystems. In particular, such estimates are submitted by the Ministry of Communities and Territories of Ukraine [19, 20]. They may be used as non-metric indicators of economic development.

Thus, for the purposes of calculations we have formed the following set of indicators: $Y_1^{(1)}$ – Index of factual volume of GRP in previous year prices, percent; $Y_2^{(1)}$ – Capital investment index, percent; $Y_3^{(1)}$ – Industrial production index, percent; $Y_4^{(1)}$ – Agricultural production index; percent; $Y_5^{(1)}$ – Foreign direct investment index, percent; $X_1^{(2)}$ – Investment and innovation development and foreign economic cooperation (rank); $X_2^{(2)}$ – Financial self-sufficiency (rank); $X_3^{(2)}$ – Labor market efficiency (rank).

The data source for determining metric indicators were materials of the State Statistics Service of Ukraine [21], and for non-metric indicators – sources [19, 20].

To provide calculations, metric indicators are converted to indicators of relative percentage increases by rule:

$$X_i^{(1)} = Y_i^{(1)} - 100, \quad (9)$$

i = 1, 2, …, 5.

In order to compact reflection of information we assign a code to each region. The relevant information is shown in Table 1. Values of metric indicators converted by formula (9) are shown in Table 2, and the values of non-metric indicators are shown in Table 3.

Table 1. Relations between title of regions and their codes.

Code	Region	Code	Region
C_1	Vinnytsia	C_13	Mykolaiv
C_2	Volyn	C_14	Odesa
C_3	Dnipro	C_15	Poltava
C_4	Donetsk	C_16	Rivne
C_5	Zhytomyr	C_17	Sumy
C_6	Zakarpattia	C_18	Ternopil
C_7	Zaporizhzhia	C_19	Kharkiv
C_8	Ivano-Frankivsk	C_20	Kherson
C_9	Kyiv	C_21	Khmelnytskyi
C_10	Kyrovohrad	C_22	Cherkasy
C_11	Luhansk	C_23	Chernivtsi
C_12	Lviv	C_24	Chernihiv

To reach normalized data we use the next rule:

$$u_{ij} = \frac{x_{ij} - x_{jmin}}{x_{jmax} - x_{jmin}}, \quad (10)$$

where u_{ij} is a i-th normalized value of indicator $X_j^{(1)}$; x_{ij} is a i-th initial value of indicator $X_j^{(1)}$; x_{jmax} and x_{jmin} are maximal and minimal values of indicator $X_j^{(1)}$; i = 1, 2, ..., 24; j = 1, 2, …, 5. We conduct the normalization process for data of each year. We denote normalized indicators as U_j, j=1, 2, …, 5. In doing so, we have taken into account the fact that all of initial indicators are incentive.

Table 2. Values of metric indexes for data of 2016-2018 transformed by formula (9).

Code	Values				
	$X_1^{(1)}$	$X_2^{(1)}$	$X_3^{(1)}$	$X_4^{(1)}$	$X_5^{(1)}$
2016					
C_1	6.5	2.5	5.3	17	-4.1
C_2	8.2	-2.5	0.2	1.9	-0.4
C_3	-1.6	15.5	-0.7	0.3	-13.4
C_4	-0.9	45.1	6.4	8.3	-28.5
C_5	5.2	27.5	5.7	16.7	-2.9
C_6	-2.7	-6.1	5.9	-3.2	1.7
C_7	-0.3	31.3	-3.1	-1.3	26.5
C_8	-1	-34.7	-4.5	1.7	-1.2
C_9	5.7	24.8	6.2	9.8	-4.8
C_10	5	47	20.3	9.4	12.3
C_11	18	46.4	39	19.3	-1.7
C_12	-0.7	30.7	-0.7	2.6	-19.3
C_13	5.6	47.6	10.5	8.5	0.3
C_14	4.2	63.4	9.2	11.6	-6.9
C_15	-2.1	32.2	0.1	3.3	0.3
C_16	0.3	-8.8	-1.9	4.9	-20.1
C_17	-3.4	35.4	-8.8	3.5	-4.6
C_18	-1.5	17.2	10.3	4.6	-2.1
C_19	2.1	35.9	5.8	6.6	-57.7
C_20	2.8	35.8	2	3.7	-4.6
C_21	4.7	23.4	4.7	8.2	-4.5
C_22	1.8	35	6.3	2.5	-3.9
C_23	-0.6	-14.1	-3.1	0	-3.3
C_24	0.6	32.5	5.8	4.5	161.9
2017					
C_1	1.8	40.0	8.2	-4.2	10.5
C_2	5.3	5.5	5.7	4.8	2.1
C_3	2.1	28.9	0.1	0.5	5.6
C_4	-4.8	44.5	-10.9	2.2	-10.7
C_5	5.0	29.3	9.5	5.8	4.9
C_6	3.1	32.4	0.3	1.4	2.5
C_7	3.1	47.4	6.2	-3.3	5.5
C_8	7.1	32.1	12.0	4.0	9.4
C_9	4.6	-5.9	10.3	-4.3	4.7
C_10	-1.4	10.5	5.5	-13.9	19.0
C_11	-16.2	2.2	-31.0	-6.0	0.4
C_12	3.8	26.0	6.0	6.1	11.6
C_13	-0.9	8.2	1.5	-9.1	-3.5
C_14	4.2	28.8	12.2	-0.6	-2.1
C_15	-2.8	33.8	-1.1	-16.8	0.6
C_16	3.5	34.6	9.3	5.0	-15.9
C_17	0.2	19.5	1.7	0.0	-4.4
C_18	5.6	42.3	8.5	11.1	-6.6
C_19	1.4	11.6	6.1	-9.9	-0.6
C_20	0.8	50.7	3.2	-0.4	8.5
C_21	6.4	11.6	1.6	12.0	8.0
C_22	-1.7	18.7	-0.9	-11.5	0.4
C_23	3.5	6.4	6.7	5.3	-25.4
C_24	2.2	34.8	-3.5	5.3	78.0
2018					
C_1	6.4	37.8	-0.8	10.6	12.3
C_2	3.3	12.1	2.2	3.2	3.3
C_3	2.5	29.4	3.0	2.7	-3.0
C_4	0.9	54.6	2.6	-9.4	8.0
C_5	6.1	2.4	-2.5	11.9	4.7
C_6	4.7	17.3	5.1	7.0	4.6
C_7	1.9	-12.0	3.6	-14.4	-0.9
C_8	5.8	-15.3	10.3	1.3	-1.1
C_9	6.5	9.8	2.0	23.8	0.2
C_10	5.8	-9.0	2.2	20.6	6.3
C_11	1.0	-8.4	-17.0	9.2	-0.3
C_12	5.4	1.9	2.4	3.8	-0.8
C_13	4.1	-12.6	4.0	6.0	10.3
C_14	0.9	-4.1	-7.6	1.1	0.4
C_15	5.8	5.5	1.5	24.0	1.8
C_16	0.6	8.7	-4.4	2.5	-0.5
C_17	3.9	8.5	10.3	11.5	0.7
C_18	2.0	3.7	-1.8	3.9	24.1
C_19	1.8	9.3	2.9	6.0	4.4
C_20	0.6	-10.7	1.1	0.5	-6.6
C_21	1.2	-3.5	-4.7	2.6	16.8
C_22	5.7	32.4	2.3	22.8	-0.4
C_23	4.5	6.7	5.8	5.3	3.4
C_24	4.2	17.7	-0.8	11.1	1.0

Table 3. Values of non-metric indexes for data of 2016-2018.

Code	Values								
	2018			2017			2016		
C_1	19	6	9	10	4	15	2	5	3
C_2	20	18	21	21	5	23	16	24	17
C_3	4	7	3	2	3	3	5	2	2
C_4	9	23	24	3	23	24	1	4	23
C_5	16	16	15	12	12	12	19	15	5
C_6	21	1	16	13	11	17	3	22	20
C_7	11	2	10	4	21	14	4	21	10
C_8	24	19	11	9	19	9	23	14	9
C_9	2	5	2	15	2	2	9	8	1
C_10	10	20	20	18	16	20	13	23	15
C_11	17	24	23	24	24	22	24	9	24
C_12	6	3	5	11	10	5	17	11	7
C_13	7	11	6	22	17	10	10	19	21
C_14	3	4	4	8	1	4	20	20	11
C_15	8	10	22	7	14	19	14	1	16
C_16	22	17	12	14	6	18	22	6	8
C_17	15	14	7	19	13	6	8	10	22
C_18	18	22	19	5	15	21	7	16	12
C_19	5	8	1	16	9	1	6	3	4
C_20	13	21	18	6	18	13	21	12	19
C_21	14	13	14	17	7	8	15	17	13
C_22	12	12	13	20	8	11	11	7	14
C_23	23	9	8	23	22	7	18	13	6
C_24	1	15	17	1	20	16	12	18	18

Further calculations will be illustrated by the example of 2018 data. The correlation matrix of metric indicators is shown in Table 4, and the matrix of Spearman's correlation coefficients between metric and nonmetric indexes is presented in the Table 5.

Next, we use the principal component method. The values of factor loadings are presented in Table 6. We also add to this table the values of the weight coefficients of the partial indicators for the construction of the integral

index, calculated taking into account the correlation coefficients of Table 4.

Table 4. Values of correlation coefficients for metric indexes for data of 2018.

Index	Values				
	$X_1^{(1)}$	$X_2^{(1)}$	$X_3^{(1)}$	$X_4^{(1)}$	$X_5^{(1)}$
$X_1^{(1)}$	1	0.0829	0.4376	0.6643	-0.0203
$X_2^{(1)}$	0.0829	1	0.1120	0.0564	0.1093
$X_{31}^{(1)}$	0.4376	0.1120	1	-0.0198	-0.1201
$X_4^{(1)}$	0.6643	0.0564	-0.0198	1	-0.0278
$X_5^{(1)}$	-0.0203	0.1093	-0.1201	-0.0278	1

Table 5. Values of Spearman's correlation coefficients between metric and non-metric indexes for data of 2018.

Index	Values		
	$X_1^{(2)}$	$X_2^{(2)}$	$X_3^{(2)}$
$X_1^{(1)}$	-0.0157	0.2913	0.1309
$X_2^{(1)}$	0.0878	0.1470	-0.0061
$X_{31}^{(1)}$	-0.0920	0.2850	0.3237
$X_4^{(1)}$	0.1454	0.0737	-0.0393
$X_5^{(1)}$	-0.1191	-0.1235	-0.2417

Table 6. Values of factor loadings for first principal component and recalculated weight coefficients for data of 2018.

Index	U_1	U_2	U_3	U_4	U_5
First principal component	0.70	0.16	0.39	0.57	-0.07
Weight coefficients	0.29	0.03	0.40	0.22	0.06

Therefore, the composite index constructed by the rule of the weighted additive convolution like formula (6) has the form:

$$I_1 = 0.29U_1 + 0.03U_2 + 0.40U_3 + 0.22U_4 + 0.06U_5.$$

Composite indexes for the data of 2017 and 2016 are calculated similarly and results are as follows:

$$I_2 = 0.42U_1 + 0.26U_2 + 0.25U_3 + 0.06U_4 + 0.01U_5$$

$$I_3 = 0.38U_1 + 0.10U_2 + 0.44U_3 + 0.07U_4 + 0.01U_5$$

The analysis of the results shows that the composite indexes have some differences in the values of the weight coefficients. The most significant indicators are the Index of the actual volume of GRP in the previous year prices and Industrial production index. The calculated values of the composite index and the rank of each region in the corresponding time period are presented in Table 7. Graphical interpretation of results is shown in Figure 1.

The sustainable development of the region's economy must be matched by an increase in the values of the composite index. According to the presented results analysis, the value of the composite index of economic development doesn't have a clear tendency of changes for the vast majority of Ukraine's regions, which leads to the conclusion that the economy of the regions doesn't meet the conditions of sustainable development. Exceptions are only Kyiv, Kirovograd, Mykolaiv, Poltava, Sumy, Cherkasy and Chernihiv regions. However, the conclusion about the sustainability of economic development for these regions may not be true.

Table 7. Values of the composite index and the rank of each region for 2016-2018.

Code	2018		2017		2016	
	Composite index values	Rank of region	Composite index values	Rank of region	Composite index values	Rank of region
C_1	0.73	7	0.79	8	0.41	6
C_2	0.55	14	0.70	14	0.34	9
C_3	0.51	15	0.71	13	0.17	21
C_4	0.39	18	0.59	20	0.31	14
C_5	0.66	10	0.83	4	0.41	5
C_6	0.69	8	0.74	10	0.18	20
C_7	0.38	19	0.84	3	0.19	18
C_8	0.76	5	0.89	2	0.10	23
C_9	0.81	1	0.64	16	0.40	7
C_10	0.76	4	0.56	21	0.55	2
C_11	0.17	24	0.06	24	0.98	1
C_12	0.64	11	0.77	9	0.21	16
C_13	0.63	12	0.55	23	0.46	3
C_14	0.26	23	0.81	6	0.45	4
C_15	0.77	3	0.60	19	0.20	17
C_16	0.30	22	0.82	5	0.18	19
C_17	0.74	6	0.64	17	0.10	24
C_18	0.46	17	0.90	1	0.29	15
C_19	0.50	16	0.63	18	0.34	10
C_20	0.35	21	0.80	7	0.31	13
C_21	0.35	20	0.74	11	0.37	8
C_22	0.78	2	0.56	22	0.32	11
C_23	0.67	9	0.67	15	0.14	22
C_24	0.59	13	0.73	12	0.31	12

The obtained results can be explained by the significant variability of metric indicator' values for the Ukraine's regions over the studied period of time. More accurate results may be obtained by constructing a single composite index for the entire data sample. However, this raises the problem of calculation of the weights of initial indicators. Taking into account the deep interconnections between all regional subsystems, it is also appropriate to consider social and environmental indicators to evaluate the economy of the region, in particular as a non-metric component of the set of initial data. The solution of these problems is the subject of further research.

5 Conclusions

Assessing the regions' economy in the context of ensuring their sustainable development remains a topical task, both at the state level and for individual entities.

Conducted studies have shown widespread use of the methodology of comprehensive evaluation in solving this task. The article deals with the approach to design a composite index for assessing the level of economic development of a region by using a weighted convolution of initial indicators. The scientific novelty of the proposed approach is the use of both metric and non-metric indicators. The metric component is used directly to form the values of the composite index, and the nonmetric

component is used to calculate the weight coefficients of the components of the composite index.

The practical implementation of this approach has shown that the economy of the vast majority of Ukrainian regions does not meet the principles of sustainable development.

The findings can be used as a basis for shaping the development strategies at both regional and national levels, as well as for evaluating the implementation of economic, social and environmental aspects of sustainable development in the regions.

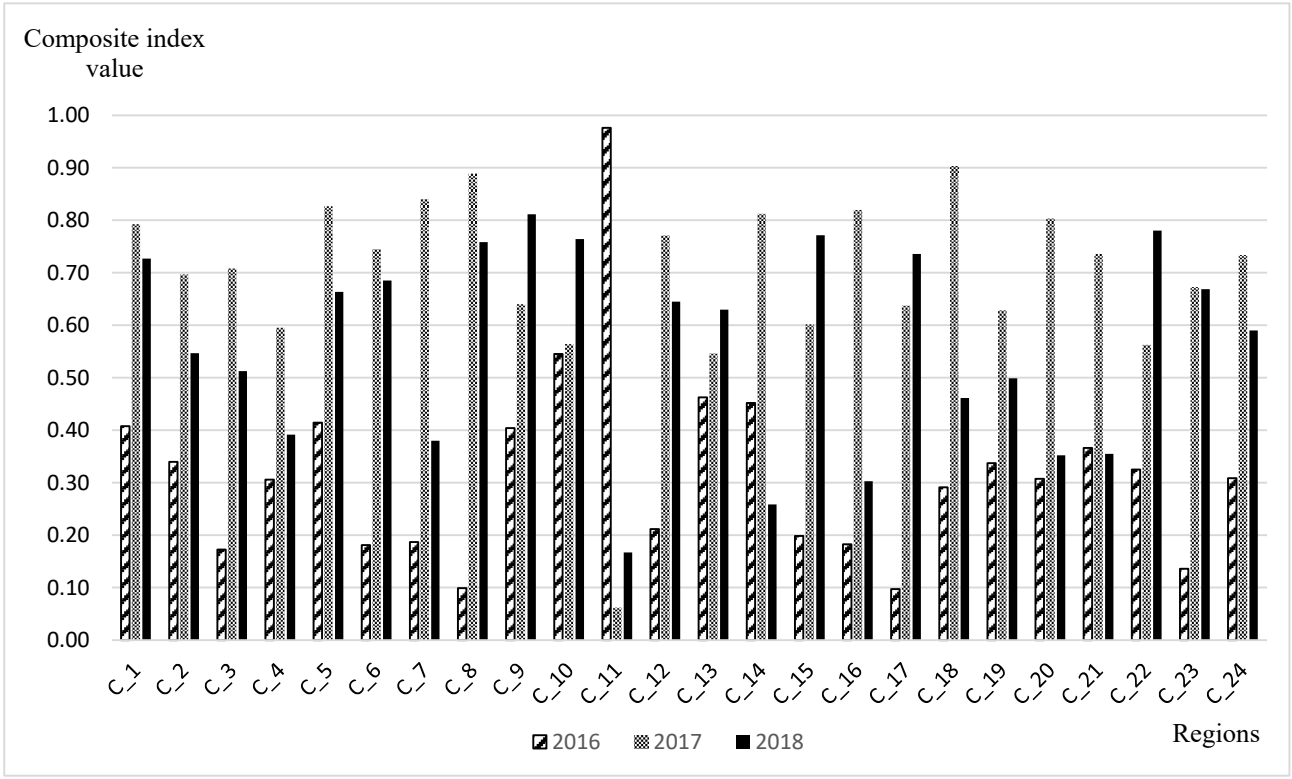

Fig. 1. Graphical interpretation of values of composite index for regions.

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An alternative approach to modeling the country's business climate in conditions of limited information

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Abstract. To date, the country's business climate characterizes the state of economic development and the results of its effectiveness. One of the key indicators that determine the business climate is the business confidence index (BCI). The paper proposes an approach to modeling the business climate of the country, which is based on the principles of information transparency, and makes it possible to assess the development trends of the studied indicator. The proposed approach is based on the taxonomy method, which allows one to identify the measure of influence of each factor included in the model and exclude the influence of the subjective assessment of the researcher. This approach has been tested on the example of Ukraine. The quarterly values of socio-economic indicators for the past twelve years (2008-2019) were taken as input data. Based on the correlation analysis, from the generated array of incoming data, only those indicators were selected that have a significant relationship with the business confidence index. It has been established that the GDP annual growth rate and retail sales have the greatest impact on the business confidence index. A forecast has been built for the trend of changes in the business confidence index (forecast accuracy of 87.55%), which proves the similarity of development trends in the country's business climate. The results obtained make it possible to analyze the cyclical development of the country's economy with high accuracy and reliability.

1 Introduction

The formed business climate of the country at the same time acts as a result and a prerequisite for its development, as it sets limits on the development of social and economic processes and determines the results of their effectiveness. That is why leading researches do not abandon the search for new methods for assessing, forecasting and improving the country's business climate.

Since the essence of the "business climate" category is poorly structured, it is quite difficult to achieve clarity in the selection of key indicators, their boundaries, and a high level of validity in choosing modeling methods. In addition, the challenge is complicated by the fact that the level of information transparency of the sources necessary for modeling the business climate differs significantly at the level of countries and separate websites. Information transparency is defined as "a qualitative attribute of information, which a certain level extent of the achievement forms an additional spectrum of the properties of that part of information that was adequately perceived and subject to processing" [1]. In this context, in practice, questions arise regarding the insufficient level of openness, accessibility, reliability of information, the impossibility of comparing it, which generally determines the risk of insufficient information transparency of aspects whose coverage makes it possible to increase the accuracy and reliability in results of modeling the business climate.

However, for the time being a powerful methodological set of tools has been formed, the use of which makes it possible in one way or another to reflect the level of the country's business climate, its structure and prospects for changes in dynamics under the influence of external factors and internal disturbances in open socio-economic systems. The assumptions that lie in the chosen methodology for assessing the business climate form a measure of error, the admissibility of which is also a separate issue of confidence in the modeling results.

Today, the key indicators that determine the business climate are the business confidence index (BCI) available from the Organisation for Economic Co-operation and Development (OECD) and the industry confidence index (ICI). The indicators are based on the principle of confidence and awareness of business entities both in relation to the current state of the country's economy and its changes. On the one hand, confidence is the result of the reliability of the estimated indicators that reflect the state of the economy and its long-term changes, and on the other, the consequence of the development of the economy. In this, the cyclical and interdependence of the laws of economic development is manifested, which also determine the quality of the country's formed business climate.

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The business confidence index is based on the mean of the balances the evaluations of entrepreneurs considering factors such as production, orders, inventories, the current economic situation and expectations of business entities regarding change in the immediate future. The industry confidence index (ICI) also based on the results of surveys of directors of industrial companies depending on the size of the enterprise. This survey considers the following questions: current level of global demand, current inventory levels, current business situation, expected production, expected employment, and the expected business situation. The advantage of these indicators is their outstripping nature, since their publication occurs earlier than other key economic indicators. In addition, the close relationship of business confidence index with the country's GDP has already been proven, the volumes of which are published later [2].

In the research S. Feuerriegela and J. Gordon [3] the business confidence index is one of the main indicator in the semantic path modeling of German economic climate. However, the weak point of indicators remains the methodology for their assessment, including the survey. This method is not without significant risks of use, including in terms of the variability of the opinions of respondents, the lack of awareness in the whole spectrum of economic issues, and so on. In addition, the use of this method of researching the business climate is quite painstaking, lengthy and costly work. Therefore, it makes sense to justify an alternative approach to assessing the country's business climate in order to maintain its leading character and simplify the receipt of assessment results.

In this direction, researchers such as Helder Ferreirade Mendonça and André Filipe Guedes Almeida [4] made successful attempts, who, as a result of studies, proved the weighty significant the impact of the credibility of monetary policy on business confidence.

Noteworthy are the many constructed business confidence indices based on the short-term memory (BiLSTM) model [5], the informative weight of which lies in the identified opportunities for analyzing inter-industry relations. The construction of artificial neural networks was successfully used to predict the business confidence index in papers [2, 6] under the influence of changes in industrial producer prices, unemployment rate, GDP annual growth rate, consumer spending, new orders, inventories, exports, imports, industrial production and steel production . Thus, the methodology for modeling the business climate of countries is expanding through the use of not only subjective, but also objective research methods with a significantly higher level of accuracy of the results. Continuing the research trend, athors offer an alternative approach to modeling the business climate.

2 Methodical approach to modelling

The approach proposed by the authors to modeling the country's business climate (Figure 1) is based on the principles of information transparency and consists of five interrelated stages.

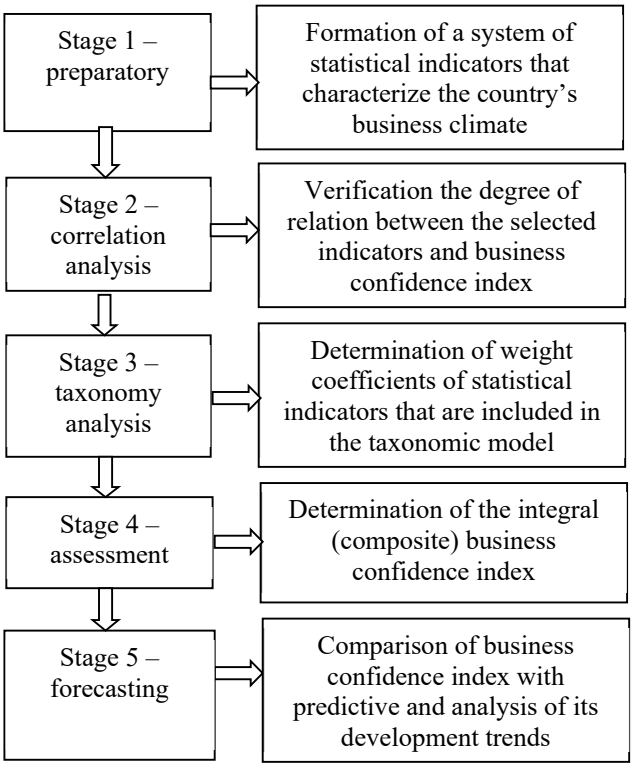

Fig. 1. Stages of modeling the country's business climate in the conditions of information transparency.

At the first stage of the proposed approach, the socio-economic indicators that characterize the country's business climate are analyzed. Based on the analysis, an information base of statistical indicators is formed. To fill the information base, official statistics of the National Bank of Ukraine [7] and the international data site "Trading Economics" [8-18] were used. The research used quarterly statistics for the period from the first quarter of 2008 to the third quarter of 2019.

At the second stage, a correlation analysis is carried out between the selected statistical indicators and the business confidence index. For further analysis, only those indicators are selected that have a correlation coefficient with the business confidence index greater than 0,7.

The third stage involves the determination of weights. To determine them, the taxonomic method is used. The essence of the method is to calculate the distance between indicators that are included in the model and included in the structure of the integral indicator. The distance between the indicators of the taxonomic model is determined using the formula [19]:

$$a_{rs} = \frac{1}{m}\sum_{i=1}^{m}|b_{ir} - b_{is}|, r, s = \overline{1,n} \qquad (1)$$

where a_{rs} – the distance between the indicators r and s;
b_r, b_s – standardized values indicators r and s;
m – number of observations;
n – number of indicators.

Matrix A, which displays the distances between the studied indicators, has the form:

$$A = \begin{bmatrix} 0 & a_{12} & \dots & a_{1n} \\ a_{21} & 0 & \dots & a_{2n} \\ \dots & \dots & 0 & \dots \\ a_{n1} & \dots & \dots & 0 \end{bmatrix}.$$

After determining the distances between the studied indicators, a critical distance is calculated that characterizes the maximum distance between two indicators:

$$a_{crit} = \max_r \min_s \quad a_{rs} \tag{2}$$

Next, for each indicator, the sum of all distances that do not exceed the critical distance is found:

$$p_j = \sum_{s=1}^{m} a_{js} \text{ for } a_{js} \le a_{crit} \tag{3}$$

Based on the data obtained, as a result of the calculations, weight coefficients are determined by the formula:

$$w_j = \frac{p_j}{\sum_{j=1}^{n} p_j} \tag{4}$$

Thus, using the taxonomic method, the values of weight coefficients of each component of the integral indicator of the country's business climate level are calculated.

The fourth stage of the proposed approach provides for an integrated assessment of the level of the country's business climate. In a formulaic form, the calculation of the composite index of business activity in a region is as follows [20]:

$$\overline{BCI_i} = \sum_{i=1}^{n} I_i \cdot w_i, \tag{5}$$

where $\overline{BCI_i}$ – the composite index of business activity value in the quarter *i*;
I_i – value of indicators, which characterizes the business climate in the quarter *i*;
i – the period;
w_i – weight coefficient of the corresponding indicator.

As a result of the calculations, obtains the time series of the business confidence index of enterprises for all analyzed time periods.

At the last stage, a comparison is made of the trends of the predicted value of the business confidence index and real. Based on the predicted value obtained, a conclusion is drawn on the future direction of the country's business climate.

The proposed approach to modeling the country's business climate makes it possible to identify the degree of influence of individual socio-economic indicators on the development path of business expectations of enterprises and to analyze the cyclical nature of the country's economy.

3 Construction and forecast of business confidence index

Approbation of the proposed approach regarding modeling the country's business climate in the conditions of information transparency was carried out on the example of Ukraine. At the first stage of modeling, the formation of an information database of input data set was carried out. It should be noted that during the formation of an array of input data, it is necessary to take into account the nature (specificity) of the country's economic development. It is also important that in a real situation, some socio-economic indicators can be interchanged, supplemented, excluded depending on the economic policy of the country. Equally important is the informational transparency of statistical information on the necessary socio-economic indicators. Considering all these aspects and the experience of domestic and foreign researchers, the authors made the assumption that the development of the country's business climate (which is characterized by the business confidence index (BCI)) is affected by a number of socio-economic indicators, such as: money supply M1, M2, M3, unemployment rate, GDP annual growth rate, consumer spending, retail sales, exports, imports, industrial production and steel production affect the development of the country's business climate, which is characterized by the business confidence index (BCI), Unemployment Rate, GDP Annual Growth Rate, Consumer Spending, Retail Sales, Exports, Imports, Industrial Production and Steel Production [8-18]. Accordingly, an information database of input statistical data for the past twelve years (2008-2019) was formed. The input data in the system of statistical indicators are given in the corresponding units of measurement; therefore, to be able to compare the data, normalization with an average value of 100 was carried out.

The second stage of modeling is to check the degree of relation between the studied indicators. Based on the results of the correlation analysis, a correlation matrix was obtained that characterizes the relationship between the input set of socio-economic indicators and the business confidence index (Table 1).

Table 1. Correlation between socio-economic indicators and the business confidence index of Ukrainian enterprises.

Economic indicators	Value of correlation
Money supply M1	-0,01
Money supply M2	-0,07
Money supply M3	-0,07
Unemployment rate	-0,44
GDP annual growth rate	0,86
Consumer spending	0,13
Retail sales	0,80
Exports	0,77
Imports	0,70
Industrial production	0,71
Steel production	0,72

Based on this matrix, we can conclude that there is a close relationship between GDP annual growth rate, retail sales, export, import, industrial production and steel production and the business confidence index of Ukrainian enterprises.

Thus, of the eleven selected socio-economic indicators, six will be included in the taxonomic model.

These indicators make up the set of socio-economic indicators that affect the country's business climate.

The next stage of modeling is the calculation of weight coefficients. According to formula (1) the distance between the indicators that are included in the taxonomic model is calculated. The distance calculation results are given in Table 2.

Table 2. Matrix of distances *A*.

Economic indicators	Retail sales	Industrial production	Steel production	Export	Import	GDP annual growth rate
Retail sales	0	8,91	14,37	14,91	15,55	7,52
Industrial production	8,91	0	10,81	13,09	14,16	4,39
Steel production	14,37	10,81	0	13,68	15,44	9,63
Export	14,91	13,09	13,68	0	7,27	11,99
Import	15,55	14,16	15,44	7,27	0	13,24
GDP annual growth rate	7,52	4,39	9,63	11,99	13,24	0

Table 2 shows that the minimum distance is present between industrial production and GDP annual growth rate. Also, a small distance is observed between export and import, GDP annual growth rate and retail sales.

After determining the distances between the studied indicators, a critical distance is calculated that characterizes the maximum distance between two indicators in accordance with formula (2). It is equal a_{crit} = 9,63.

By the formula (3), the sum of all distances that do not exceed the critical one is calculated for all indicators. The calculation results are shown in Table 3.

Table 3. Value of coefficient p_j.

Economic indicators	Coefficient, p_j
Retail sales (RS)	16,43
Industrial production (IP)	13,30
Steel production (SP)	9,63
Exports	7,27
Imports	7,27
GDP annual growth rate (GDP_AGR)	21,53

In accordance with the above methodology, the next step is to calculate the weighting coefficients. By the formula (4), the set of weight coefficients was obtained, which is shown in Table 4.

Table 4. The set of weight coefficient w_i.

Economic indicators	Weight coefficient, w_i
Retail sales (RS)	0,218
Industrial production (IP)	0,176
Steel production (SP)	0,128
Export	0,096
Import	0,096
GDP annual growth rate (GDP_AGR)	0,286

Analyzing the data in Table 4, it is clear that the GDP annual growth rate (0,286) turned out to be the most significant factor, so we can say that it has the greatest impact on the business confidence index of Ukrainian enterprises. The volume of exports and imports have the least impact on the level of the business climate of the country and is only 0,096. Weighted socio-economic indicators are integral components of the composite business confidence index.

The fourth stage of modeling is the calculation of the composite index of business activity, that is, the business confidence index, which determines the level of the business climate of the studied country as a whole. Using the obtained values of weighting coefficients and normalized socio-economic indicators, the forecast value of the composite index of business activity is obtained as follows:

$$\overline{BCI_i} = W_1 \cdot RS_i + W_2 \cdot IP_i + W_3 \cdot SP_i + W_4 \times \\ \times Exports_i + W_5 \cdot Imports_i + W_6 \times \\ \times GDP_AGR_i = 0{,}218 \cdot RS_i + 0{,}176 \times \\ \times IP_i + 0{,}128 \cdot SP_i + 0{,}096 \cdot Exports_i + \\ +0{,}096 \cdot Imports_i + 0{,}286 \cdot GDP_AGR_i \quad (6)$$

The dynamics of the business confidence index and the composite index of business activity obtained by the taxonomic method for Ukrainian enterprises are shown in Figure 2. The average absolute error in predicting the composite index of business activity (MAPE) is 12,45%.

According to Figure 2, authors note that the actual level of the business confidence index differs from the calculated composite index by an average of 9.65%, which is acceptable and does not reduce the accuracy and information content of the calculated index. The trends of the studied indicators are characterized by a high level of volatility, in particular during the crisis period for the country (2008-2009, 2014-2015), during the intermediate period of stabilization between them, the fluctuation trends decrease, but the volatility of the trends is significant.

For the research period, there are two local minimums according to the fact and calculated indicators, the first was recorded in the first quarter of 2009 – 72 (business confidence index) and 81,11 (composite index), the second in the first quarter of 2015 with 83,5 (business confidence index) and 80,96 (composite index). The indicated local minimum generate a trend support line for the period under research, a position below which signals a deterioration in the situation and the formation of a new downtrend. Studying the local maximum of the indicator trends, authors note that for the period under review, the trends were corrected; therefore, three local maximum can be distinguished. The first maximum at the beginning of the research period in the first quarters of 2008 with values of 140,1 (business confidence index) and 113,35 (composite index). The second local maximum was recorded in the first quarter of 2011 with values of 123,2 (business confidence index), however, the composite index was outstripping, so its local maximum with a value of 110,91 was recorded a quarter earlier in the fourth

quarter of 2010. The third local maximum was recorded in the first quarter 2018 with a value of 120,6 (business confidence index), however, the composite index again outstripped the trend of the actual indicator and its local maximum was recorded a quarter earlier in the fourth quarter of 2017 with a value of 105,8. In general, local maximums of the trends of the studied indicators form a resistance line, the violation of which gives grounds to assert the formation of a new upward trend.

According to the forecast data of the composite index, the index is forecasted to be at the level of 100,81 for the first quarter of 2019, which is 97,19% of the same indicator in the fourth quarter of 2018, the index value is forecasted at 104,023 for the second quarter of 2019, and 103,91 for the third quarter of 2019. The average value of the composite index according to 2019 is 87,5% of the actual business confidence index value.

In general, a range is visualized in which the trends of the studied indicators fluctuate, which determines the basic level of the country's business climate, limited to 90-120 points. Violation of this range is possible through the formation of a new upward trend due to the implementation of qualitative changes in the directions of development of investment platforms, park mechanisms, activation of internal processes of self-organization and hidden resource potential in the country, in the conditions of state support for the development of technology transfer, protection of investors' interests, control of corruption and other.

In addition, the most important thing is that the tendency of the studied indicators is identical, in particular, during the period of the emergence of crisis phenomena (beginning of 2009, end of 2014 and beginning of 2015), the decrease in the level of indicators is similar, which suggests that there is a real possibility of using the alternative to business confidence index, which calculated by the taxonomic method of in order to predict the business climate in conditions of limited information transparency.

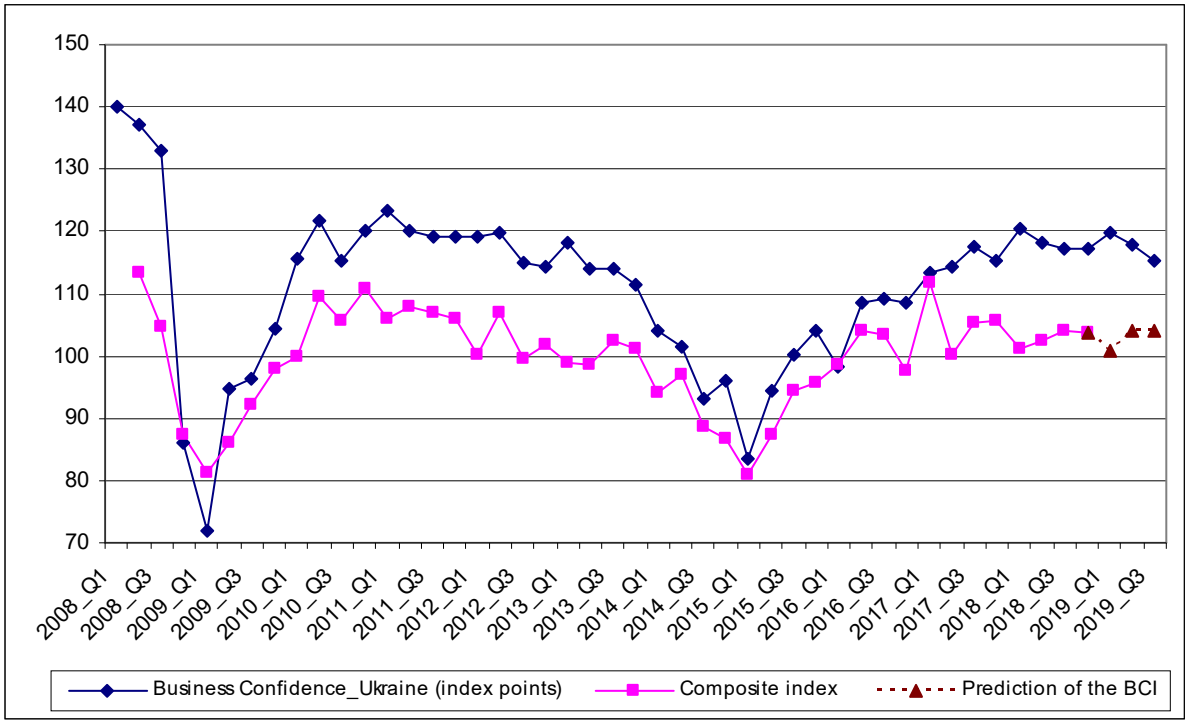

Fig. 2. The dynamics of the business confidence index and the composite index of business activity.

4 Conclusions

Using a reasonable alternative approach to modeling the country's business climate has proved the possibility of implementing a simplified procedure for assessing the trends of its changes using the composite index of business activity calculated by the authors. The methodology of the study consists in substantiating the use of the taxonomy method for calculating this index and studying the identity of its dynamics to changes in the generally accepted business confidence index. An analysis of the trends of the calculated composite and actual indices of business confidence proved the similarity of trends, including during the formation of local maximums and minimums.

A variable component in the proposed alternative approach is a combination of key statistical indicators. The set of statistical indicators that is justified during the research, which determines the business climate, is basic for the countries that are developing. Whereas for developed countries, the set of key indicators is desirable to review in accordance with the characteristics of the development of their economies. The problem for the implementation of an alternative approach remains limited access to key statistics, which is the result of a policy of ensuring information transparency in different countries.

The prospect of a reasonable approach is that in the case of ensuring the necessary level of information transparency of input data, there is a real opportunity by statistical methods to ensure the identity of the index trends: the business confidence index and the composite index of the business activity proposed by the authors.

The effectiveness of the proposed alternative approach is manifested in saving costs for generating input data for assessing the country's business climate by using official statistics instead of survey results, the subjectivity of which is much higher. In general, the implemented alternative approach is unified, can serve as the basis for further deepening the methodological provisions for studying the business climate of countries with high accuracy and reliability of the results.

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Economic and mathematical modeling of industrial enterprise business model financial efficiency estimation

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Abstract. The article proposes two methods for evaluating the financial efficiency of a business model of industrial enterprises. In order to evaluate the financial efficiency of the business model of an industrial enterprise, a system of single indicators for assessing the financial condition of the enterprise by such components as financial stability, liquidity and solvency, business activity and profitability was formed. Fishburne's rule weights the major components of an integral measure of an enterprise's business model financial performance. In addition, an integral measure of the financial performance of the business model is modeled using the fuzzy set method and taxonomic analysis, which will help to evaluate the financial performance level of the business model more objectively. The comparative analysis of the obtained results by different methods of calculation of integral indicators is carried out.

1 Introduction

An important issue in shaping the business model of an enterprise is the evaluation of its effectiveness, and especially of financial efficiency, which is a matter of principle for businesses focused on obtaining an economic effect.

Studying various scientific sources which cover problems of estimation of business models of enterprises [1, 2, 3, 4, 5] we have concluded that in modern works there are many approaches to formation of modern business models of enterprises, but we are offered two approaches for evaluating the financial performance of an industrial enterprise business model, according to which it is proposed to use an integral measure of the economic efficiency of an enterprise business model using the Harrington desirability function and the taxon method endemy, in addition to a comparative analysis of the results of calculations for integrated parameter with both methods.

2 Background

Kayaoglu Nuri in dissertation [1] proposed hierarchical business model evaluation approach, on the one hand, acts as a skeleton for the businesses by providing a structured way of thinking; it provides a strong foundation for abstract level analysis of relations, gains, and faults that form the core of the businesses. On the other hand, the contributed concepts, evaluation model approach, and the evaluation tool, give us enough confidence to place this work as a contribution under strategic management in the management context. Deviating from the commonly used static methods, in this work, they propose a dynamic solution. The authors [2] elaborate a categorization of tools and methodologies concerning two major logics of evaluation: analytical/effectual and quantitative/qualitative. This sheds light upon the dominant mode of evaluation within different stages of digital BMI processes. A. Batocchio, A. Ghezzi and A. Rangone in their article [3] proposed method (roadmap for implementation of business models – RIBM) is composed of nine steps, and seven initials conditions (limitations). Such conditions reduce its complexity (e.g. performance management system is defined in the company). In the paper [4] author present the results of a review analysis on business model evaluation methods and their utility for entrepreneurs in developing and evaluating their business models. In addition, author indicate, there is a certain gap between the academic perspective to business models and the entrepreneur's perspective, there being an ever-growing need for practical and operational instruments.

Although there has been an important amount of research on business models, defining the business model concept, taxonomy of business models, decomposing business models and identifying their components, ontology and design tools; the research on business model is still an area that has not been sufficiently investigated.

3 Methodology

The financial performance of an industrial enterprise is evaluated by a comprehensive system of indicators of financial stability, liquidity and solvency, business activity and profitability. All these indicators are well

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known. However, in order to determine the overall assessment of financial performance, we propose to form an integral indicator of evaluating the financial performance of an enterprise business model.

Thus, the process of evaluating the financial performance of a business model of an industrial enterprise (fig. 1.)

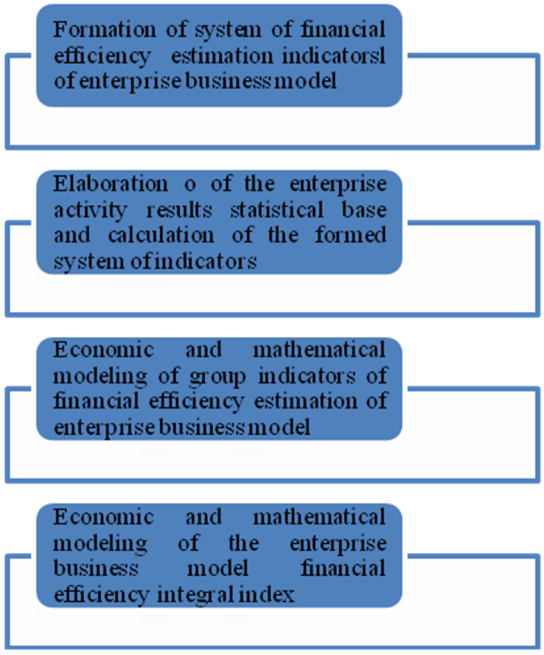

Fig. 1. The stages of economy and mathematical modelling of the enterprise business model financial efficiency integral index.

The financial performance of a business model of an industrial enterprise can be estimated on the basis of values of indicators values generalized groups:

$$I_f = f(Y_1; Y_2; Y_3; Y_4) \qquad (1)$$

where Y_i is the corresponding *i*-th group of indicators. Given that each value of Y_i in model (1) is also an integral indicator of the evaluation of each of the evaluation directions, the given model is slightly modified.

$$Y_i = f(f_1(x_{1.1}; x_{1.2}; \dots x_{1.n}); f_2(x_{2.1}; x_{2.2}; \dots x_{2.m}); f_3(x_{3.1}; x_{3.2}; \dots x_{3.l}); f_4(x_{4.1}; x_{4.2}; \dots x_{4.k})) \qquad (2)$$

where $x_{1.1}; x_{1.2}; \dots x_{1.n}$ – single indicators of financial sustainability assessment;
$x_{2.1}; x_{2.2}; \dots x_{2.m}$ – single liquidity and solvency indicators;
$x_{3.1}; x_{3.2}; \dots x_{3.l}$ – single indicators of business activity evaluation;
$x_{4.1}; x_{4.2}; \dots x_{4.k}$ – single profitability metrics;
f_1, f_2, f_3, f_4 – integral indicators of each of an industrial enterprise business model identified component financial efficiency.

Table 1 summarizes the individual indicators for assessing the financial performance of a business model of an industrial enterprise.

Table 1. Indicators of selected components for economic and mathematical modeling of the integral indicator of the enterprise business model financial efficiency evaluation.

The name of the component	The name of a single metric	The designation used in the model
Component of financial stability (f_1)	Financial independence ratio	$x_{1.1}$
	Financial dependency ratio	$x_{1.2}$
	Financial Risk Ratio	$x_{1.3}$
	Coefficient of financial stability	$x_{1.4}$
	Ratio of mobile and immobilized assets	$x_{1.5}$
	Long-term commitment ratio	$x_{1.6}$
	Ratio of current liabilities	$x_{1.7}$
	Financial leverage ratio	$x_{1.8}$
	Maneuverability factor of own	$x_{1.9}$
	Coefficient of supply of inventories with own funds	$x_{1.10}$
	Working capital maneuverability factor	$x_{1.11}$
	Fixed Assets Index	$x_{1.12}$
	The coefficient of the real value of fixed assets	$x_{1.13}$
Solvency and liquidity component (f_2)	Solvency ratio	$x_{2.1}$
	Absolute liquidity ratio	$x_{2.2}$
	Quick liquidity ratio	$x_{2.3}$
	Critical liquidity ratio	$x_{2.4}$
	Coefficient of coverage	$x_{2.5}$
	Ratio of current and total assets	$x_{2.6}$
Business activity component (f_3)	Ratio of total capital turnover	$x_{3.1}$
	Mobile turnover rate	$x_{3.2}$
	The turnover ratio of tangible working capital	$x_{3.3}$
	Receivables turnover ratio	$x_{3.4}$
	The average term of receivables turnover	$x_{3.5}$
	Ratio of accounts payable	$x_{3.6}$
	The average term of turnover of accounts payable	$x_{3.7}$
	Fund return on fixed assets and other fixed assets	$x_{3.8}$
	Equity turnover ratio	$x_{3.9}$
The profitability component (f_4)	The rate of return on assets	$x_{4.1}$
	Return on equity ratio	$x_{4.2}$
	Return on Equity Ratio	$x_{4.3}$
	Profitability ratio	$x_{4.4}$
	The profitability ratio of products	$x_{4.5}$

Next, it is necessary to calculate the significance of the factors. To do this, we use the Fishburn rule, which allows us to determine the level of significance of indicators

based on their ranking. If you order the system of indicators according to the degree of their decrease, the significance of the f_i-th component should be determined by the formula (3):

$$r_i = \frac{2(N-i+1)}{(N+1)N} \quad (3)$$

where r_i is the weighting factor of the i-th component;
N – the number of indicators of the population;
i – sequence number (rank) of the population index.

Investigating scientific works that raised the issues of ranking components of the financial performance of enterprises, it was found that the priority indicators that characterize the financial condition of the company are indicators of profitability and business activity beyond solvency and liquidity and recent financial stability. Table 2 shows the results of calculating the degree of significance of each of the components.

Table 2. Calculation of component constituents significance degrees and single indicators.

The name of the component	The specific weight of the component
The profitability component (f_4)	0,4
Business activity component (f_3)	0,3
Solvency and liquidity component (f_2)	0,2
Component of financial stability (f_1)	0,1

Table 3 shows the estimated values of financial ratios for the company JSC Ukrtransnafta for 2014-2018 years.

It should be noted that when analyzing even some of the indices that characterize the financial efficiency of an industrial enterprise's business model, ambiguous situations are possible when, by these certain indicators, financial efficiency can acquire both positive and negative trends. Therefore, to solve this problem, we propose the use of methodology and mathematical apparatus of the theory of fuzzy sets.

The basis of the notion of fuzzy sets is the idea that the constituent elements of a given set, which have a common property, can possess this property to varying degrees (and to a different extent), and therefore belong to this set with different degrees [5]. Therefore, it is necessary to use a single universal generalized indicator.

However, if a business model's financial performance is assessed on the basis of several financial indicators, then it would be advisable to carry it out using some integral metric to construct a generalized Harrington function:

$$D = \sqrt[n]{\prod_{i=1}^{n} d_i} \quad (4)$$

$$d_i = \exp(-\exp)(-y_i)) \quad (5)$$

where n is the number of indicators used to evaluate the financial performance of a business model of an industrial enterprise;
d_i – is a partial function that is defined according to the Harrington scale;
y_i – a single measure of the financial performance of a business model of a business enterprise in dimensionless form.

Table 3. Estimated values of financial ratios for the company JSC Ukrtransnafta for 2014-2018 years [8].

The name of a single metric	2014	2015	2016	2017	2018
Financial independence ratio	0,83	0,83	0,85	0,80	0,84
Financial dependency ratio	0,17	0,17	0,15	0,20	0,16
Financial Risk Ratio	0,20	0,20	0,17	0,25	0,19
Coefficient of financial stability	5,06	4,96	5,75	4,06	5,34
Ratio of mobile and immobilized assets	0,09	0,17	0,39	0,36	0,44
Long-term commitment ratio	14,26	6,83	4,54	6,93	15,78
Ratio of current liabilities	0,12	0,21	0,22	0,45	0,37
Financial leverage ratio	2,82	1,38	0,79	1,70	2,96
Maneuverability factor of own	0,10	0,17	0,33	0,33	0,36
Coefficient of supply of inventories with own funds	18,53	33,42	2,82	2,58	2,19
Working capital maneuverability factor	0,05	0,03	0,35	0,39	0,46
Fixed Assets Index	1,10	1,03	0,84	0,91	0,83
The coefficient of the real value of fixed assets	0,91	0,84	0,69	0,71	0,63
Solvency ratio	0,87	1,31	4,63	1,69	0,96
Absolute liquidity ratio	0,87	1,31	4,63	1,69	0,97
Quick liquidity ratio	3,92	4,01	5,55	1,83	2,81
Critical liquidity ratio	3,92	4,01	5,58	1,84	2,84
Coefficient of coverage	4,15	4,14	8,65	3,01	5,22
Ratio of current and total assets	0,08	0,14	0,28	0,27	0,31
Ratio of total capital turnover	0,10	0,13	0,16	0,18	0,27
Mobile turnover rate	1,13	0,94	0,58	0,69	0,89
The turnover ratio of tangible working capital	20,92	31,30	1,62	1,77	1,95
Receivables turnover ratio	8,00	20,77	20,73	15,47	53,11
The average term of receivables turnover	45,65	17,57	17,61	23,60	6,87
Ratio of accounts payable	4,68	3,87	4,97	2,07	4,66
The average term of turnover of accounts payable	77,96	94,20	73,39	176,49	78,38
Fund return on fixed assets and other fixed assets	0,10	0,16	0,22	0,25	0,39
Equity turnover ratio	0,11	0,16	0,19	0,23	0,32
The rate of return on assets	0,03	0,06	0,07	0,10	0,10
Return on equity ratio	0,03	0,07	0,08	0,13	0,12
Return on Equity Ratio	1,50	2,96	3,30	4,65	3,18
Profitability ratio	0,29	0,69	0,66	0,64	0,43
The profitability ratio of products	0,21	0,59	0,43	0,55	0,39

Harrington's generalized function is a quantitative, unambiguous, single, and universal measure of the quality of an object under study, and if you add such qualities as adequacy, efficiency, and statistical sensitivity, it becomes clear that it can be used as an optimization criterion.

The Harrington scale is conventionally divided into five sections, which characterize the dimensionless dimensions of the indicators under consideration. To apply the Harrington scale, all the studied parameters must be dimensionless in accordance with the abscissa and calculate the values of the partial functions of Harrington by equation (4). The number of partial functions obtained equals the number of indicators of evaluating the financial efficiency of an industrial

enterprise's business model.

The following is a generalized measure of performance, based on the values of the function d_i by the formula

In the course of the research, certain simplifications were made in the integral assessment of the financial efficiency of an industrial enterprise's business model based on a fuzzy multiple analysis [5, 6, 7]:

1. The fuzzy multiple approach was implemented only for quantification, in particular when calculating key financial ratios.
2. The choice of financial analysis ratios is not straightforward. Therefore, the proposed calculation method will also work with the use of other financial indicators.
3. The financial statements of the enterprises were selected from open sources of information which we believe to be fairly reliable.
4. The financial analysis was carried out without taking into account the factors of inflation, seasonality, etc.

Analysis of financial statements of industrial enterprises consists of the calculation of certain financial and economic indicators - ratios of liquidity and solvency, financial stability, profitability, business activity.

An important step in the process of analyzing the effectiveness of activity is the prediction of the integral indicator of financial efficiency business model of an industrial enterprise.

To determine the overall level of financial performance of a business model of an industrial enterprise, it is proposed to use some integral indicator, on the basis of which we can make a clear conclusion about the level of efficiency. The basis of such an indicator is the idea of transforming the natural values of each criterion for evaluating the financial efficiency of a business model of an industrial enterprise into a dimensionless form and further calculating the integral indicator. An integrated measure of the financial performance of an industrial enterprise business model (the Harrington generalized function is proposed as such) takes a value from 0 to 1.

Since the desirability function of Harrington uses dimensionless financial performance of a business model in dimensionless form, it is necessary to carry out the normalization (standardization) of these indicators.

The procedure for standardization of indicators leads to elimination of measurement units and alignment of indicator values.

Using element multiplicity w described by n-signs, each unit can be interpreted as a point of n-dimensional space with coordinates equal to the value of n attributes for the analysed unit. Let us represent the matrix as follows:

$$X = \begin{bmatrix} x_{11}x_{12}\dots x_{1k}\dots . x_{1n} \\ x_{21}x_{22}\dots x_{2k}\dots x_{2n} \\ \dots\dots\dots\dots\dots\dots\dots \\ x_{i1}x_{i2}\dots . x_{ik}\dots . x_{in} \\ \dots\dots\dots\dots\dots\dots\dots \\ x_{w1}x_{w2}\dots . x_{wk}\dots . x_{wn} \end{bmatrix} \quad (6)$$

where: w is the number of study periods, n is the number of indicators of each recreational forest management potential, x_{ik} – indicator value k of each specific component for a year ($k = 1 \div n$, $i = 1 \div w$).

The differentiation of the observation matrix attributes is based on the study of each attribute impact on the level of recreational forest management potential, as well as the distribution of attributes by the positive (as a set of stimulants) and negative impact (a set of stimulants) on the recreational forest management potential. A high level of a certain attribute will determine a positive character, a low level will determine a negative character of the comparison attribute. This differentiation will make it possible to choose reference points in the variation of sustainability level indicators of land regulation [10].

An important step in the construction of integral performance indicators for the business model of an industrial enterprise is to normalize the various unit indices of the efficiency of using a set of components for this procedure, we will use a method of aggregating features based on the so-called theory of "additive value", according to which the value of the whole is equal to the value of the whole components. If the signs of the set have different units of measurement, then additive aggregation requires bringing them to one basis, that is, the previous normalization [8].

Normalization for constructing an integral metric constructed using the Harrington function is carried out by the formulas:

for "higher the better" metrics:

$$z_{ik} = \frac{x_{ik} - x_{min}}{x_{max} - x_{min}} \quad (7)$$

for "less is better" metrics:

$$z_{ik} = \frac{x_{max} - x_{ik}}{x_{max} - x_{min}} \quad (8)$$

where: z_{ik} – normalization indicator k, in period i;
x_{ik} – indicator k, in period i before normalization;
x_{min} – minimum indicator k, in period i before normalization;
x_{max} – maximum indicator k, in period i before normalization.

The task of normalization of indicators is the transition to such a scale of measurements, when the "best" value of the indicator corresponds to the value 1 and the "worst" – the value 0. From the point of view of mathematics, it is the task of normalizing variables, and in terms of statistics – the transition from absolute to normalized values of indicators that vary from 0 to 1 and already by their magnitude characterize the degree of approximation to the optimum value, which can also be interpreted in percentage: 0 corresponds to 0%, 1 to 100% [9].

Table 3 shows the criterion parameters of the level of financial efficiency of a business model of an industrial enterprise.

This scale was chosen because it allowed several features to be combined with a single unit of measurement in the context of linguistic assessments. In doing so, it was possible to quantify on a dimensionless scale the level from completely unacceptable (0) to completely

acceptable (1).

Table 4. Critical parameters of the level of financial efficiency of an industrial enterprise's business model.

The level of financial efficiency of a business model of an industrial enterprise	Numerical values	Potential reserve (%)
Very high	0,8 – 1	0 – 20
High	0,64 – 0,8	20 – 36
Average	0,37 – 0,64	36 – 63
Low	0,2 – 0,37	63 – 80
Very low	0,0 – 0,2	80 – 100

As a result of observation matrix standardization, we obtain the following matrix:

$$Z = \begin{bmatrix} z_{11}z_{12}\dots z_{1k}\dots . z_{1n} \\ z_{21}z_{22}\dots z_{2k}\dots z_{2n} \\ \dots\dots\dots\dots\dots\dots\dots \\ z_{i1}z_{i2}\dots . z_{ik}\dots . z_{in} \\ \dots\dots\dots\dots\dots\dots\dots \\ z_{w1}z_{w2}\dots . z_{wk}\dots . z_{wn} \end{bmatrix} \quad (9)$$

Table 5 shows the results of standardization individual indicators.

Table 6 summarizes the calculations of the integral indicators of each of the components of the financial efficiency of an industrial enterprise's business model.

Figure 2 shows the dynamics of the integrated financial performance indicator of a business model of an industrial enterprise calculated using the Harrington function for 2014-2017.

In order to formulate clear conclusions about the level of financial efficiency of the business model of the enterprise, we propose to calculate another integral indicator using a taxonomic method, and to carry out standardization based on the determination of deviations of individual indicators from their average value.

For this stage, we use a taxonomic method based on determination of taxonomic indicators of each component. The determination of taxonomic indicators begins with identification of elements of observation matrix *X*, its elements are represented by indicator values expressed in units, specific for each indicator. The standardization shall be performed. The procedure for standardization of indicators leads to elimination of measurement units and alignment of indicator values.

The differentiation of the observation matrix attributes is based on the study of each attribute impact on the level of recreational forest management potential, as well as the distribution of attributes by the positive (as a set of stimulants) and negative impact (a set of stimulants). A high level of a certain attribute will determine a positive character, a low level will determine a negative character of the comparison attribute. This differentiation will make it possible to choose reference points in the variation of sustainability level indicators of land regulation [10].

The attributes are standardized according to the formula:

$$z_{ik} = \frac{x_{ik} - \bar{x_k}}{s_k} \quad (10)$$

Table 5. Standardized unit financial performance indicators of an industrial enterprise's business model.

The name of a single metric	2014	2015	2016	2017	2018
Financial independence ratio	0,58	0,58	0,69	0,37	0,64
Financial dependency ratio	0,58	0,58	0,69	0,37	0,64
Financial Risk Ratio	0,59	0,59	0,69	0,37	0,62
Coefficient of financial stability	0,58	0,56	0,69	0,37	0,63
Ratio of mobile and immobilized assets	0,37	0,45	0,65	0,63	0,69
Long-term commitment ratio	0,42	0,64	0,69	0,63	0,37
Ratio of current liabilities	0,69	0,62	0,61	0,37	0,46
Financial leverage ratio	0,39	0,62	0,69	0,57	0,37
Maneuverability factor of own	0,37	0,47	0,66	0,66	0,69
Coefficient of supply of inventories with own funds	0,55	0,69	0,38	0,37	0,37
Working capital maneuverability factor	0,38	0,37	0,62	0,65	0,69
Fixed Assets Index	0,37	0,46	0,68	0,61	0,69
The coefficient of the real value of fixed assets	0,69	0,62	0,45	0,47	0,37
Solvency ratio	0,37	0,41	0,69	0,45	0,38
Absolute liquidity ratio	0,37	0,41	0,69	0,45	0,38
Quick liquidity ratio	0,57	0,57	0,69	0,37	0,46
Critical liquidity ratio	0,56	0,57	0,69	0,37	0,47
Coefficient of coverage	0,44	0,44	0,69	0,37	0,51
Ratio of current and total assets	0,37	0,46	0,66	0,65	0,69
Ratio of total capital turnover	0,37	0,43	0,50	0,54	0,69
Mobile turnover rate	0,69	0,59	0,37	0,44	0,57
The turnover ratio of tangible working capital	0,59	0,69	0,37	0,37	0,37
Receivables turnover ratio	0,37	0,47	0,47	0,43	0,69
The average term of receivables turnover	0,37	0,62	0,62	0,57	0,69
Ratio of accounts payable	0,67	0,58	0,69	0,37	0,66
The average term of turnover of accounts payable	0,68	0,64	0,69	0,37	0,68
Fund return on fixed assets and other fixed assets	0,37	0,44	0,52	0,55	0,69
Equity turnover ratio	0,37	0,45	0,50	0,57	0,69
The rate of return on assets	0,37	0,52	0,57	0,69	0,69
Return on equity ratio	0,37	0,51	0,55	0,69	0,67
Return on Equity Ratio	0,37	0,53	0,57	0,69	0,56
Profitability ratio	0,37	0,69	0,67	0,66	0,49
The profitability ratio of products	0,37	0,69	0,57	0,66	0,54

Table 6. Integral indicators of financial performance components of an industrial enterprise business model.

Components of financial efficiency of an industrial business model	Specific gravity components	2014	2015	2016	2017	2018
Component of financial stability (f_1)	0,1	0,49	0,55	0,62	0,48	0,54
Solvency and liquidity component (f_2)	0,2	0,44	0,47	0,69	0,43	0,47
Business activity component (f_3)	0,3	0,48	0,54	0,51	0,46	0,63
The profitability component (f_4)	0,4	0,37	0,58	0,58	0,68	0,58
Integral indicator of financial efficiency of business model of industrial enterprise		0,43	0,55	0,59	0,54	0,57

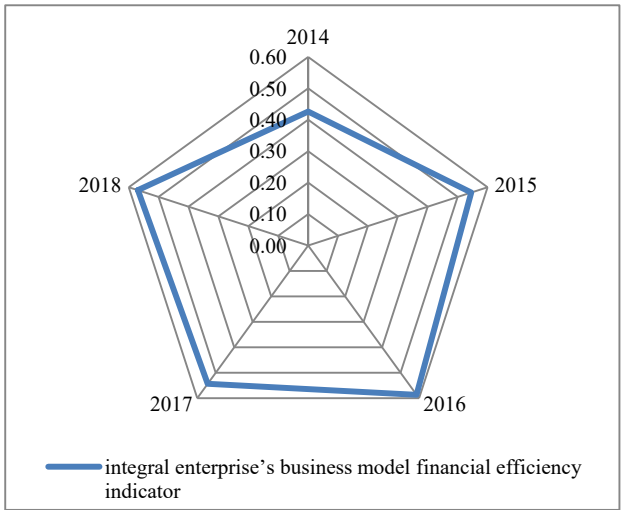

Fig. 2. The dynamics of the integrated financial performance indicator of a business model of an industrial enterprise calculated using the Harrington function for 2014-2017.

when

$$\bar{x_k} = \frac{1}{w}\sum_{i=1}^{w} x_{ik} \quad (11)$$

$$S_k = \sqrt{\frac{1}{w}\sum_{i=1}^{w}\left(x_{ik} - \bar{x_k}\right)^2} \quad (12)$$

where: z_{ik} – standardized value of indicator k for the i-th study period; x_{ik} – standardized value of indicator k for the i-th study period; x_k – arithmetic mean of k indicator; S_k – standard deviation of k indicator; w – a number of periods.

By multiplying values of each standardized attributes by the hierarchy coefficient, corrected values of the corresponding attribute are used for taxonomic analysis.

The next step is the problem analysis of observation matrix differentiation. All variables are divided into stimulants and disincentives. The indicators of each component are divided into two groups based on the impact character of each of them on recreational forest management potential. Indicators, having a positive effect on recreational forest management potential, are considered stimulants, in contrast to the negative indicators, having a negative effect – the stimulants and, thus, reducing the level of recreational forest management potential [11].

Distribution of indicators into stimulants and disincentives serves as the basis to develop the so-called standard, represented by point $\mathbf{P_o}$ with coordinates: z_{01}, z_{02}, …, z_{0n}:

$$\begin{aligned} z_{0s} &= \max z_{rs}, if\ \ s \in I \\ z_{0s} &= \min z_{rs}, if\ \ s \notin I\ (s = 1,2...n) \end{aligned} \quad (13)$$

where: I is a set of stimulants, z_{rs} is a standardized value of the exponent s of a specific block of costs for period r. The distance between individual unit points and point $\mathbf{P_o}$, representing the standard of cost level, is expressed as C_{i0} and calculate as follows:

$$C_{i0} = [\sum_{s=1}^{n}(z_{is} - z_{0s})^2]^{\frac{1}{2}} \quad (i = 1, \ \ldots\ldots, \ w) \quad (14)$$

The obtained distances are considered as initial values used to calculate the indicator of recreational forest management potential:

$$d_i = 1 - \frac{c_{i0}}{c_0} \quad (15)$$

$$\bar{c_0} = \frac{1}{w}\sum_{i=1}^{w} c_{i0} \quad (16)$$

$$S_0 = \left[\frac{1}{w}\sum_{i=1}^{w}(c_{i0} - \bar{c_0})^2\right]^{\frac{1}{2}} \quad (17)$$

This indicator is interpreted as follows: it assumes a high value at high stimulus values and a low value at low stimulus values. The closer the figure is to one, the higher the level of recreational forest management potential. The indicator can serve for statistical characterises of elements infinity. It is possible to estimate the "average" level of the indicators, achieved within a certain period of time characterizing the analysed problem [12].

The results of the taxonomic analysis are summarized in table 7.

Table 7. Integral indicators of the financial performance components of an industrial enterprise business model are calculated using the taxonomy method.

Components of financial efficiency of an industrial business model	**Specific gravity components**	**2014**	**2015**	**2016**	**2017**	**2018**
Component of financial stability (f_1)	0,1	0,22	0,41	0,59	0,10	0,32
Solvency and liquidity component (f_2)	0,2	0,17	0,34	0,48	0,08	0,36
Business activity component (f_3)	0,3	0,26	0,46	0,35	0,10	0,63
The profitability component (f_4)	0,4	0,06	0,58	0,62	0,93	0,60
Integral indicator of financial efficiency of business model of industrial enterprise		0,43	0,16	0,48	0,51	0,43

Figure 3 shows the dynamics of the integral indicator of financial efficiency of a business model of an industrial enterprise calculated using the taxonomy method for 2014-2017.

4 Results

Thus, from the obtained results of the calculations, we can conclude unequivocally that during the analyzed period the financial efficiency of the business model of the studied enterprise is at an average level, and it should be noted a positive trend of growth of these indicators at the end of the period relative to the base period of the study. The increase in the financial performance indicator of Ukrtransnafta's business model has gone from 0,43 (43%) in 2014 to 0,57 (57%) in 2018 by an indicator calculated using the Harrington function and from 0,16 (16%) in 2014 to 0,53 (53%) in 2018 according to the taxonomic method. The growth of the integral indicator was largely due to the increase in the level of profitability of the

enterprise, which show us the integral indicators of the profitability components in Tables 6 and 7. Such results were obtained as a result of the increase of profit of the enterprise from 688,689 thousand UAH in 2014 to 1463,239 thousand UAH. at the end of the analyzed period, which led to an increase in the level of individual profitability indicators.

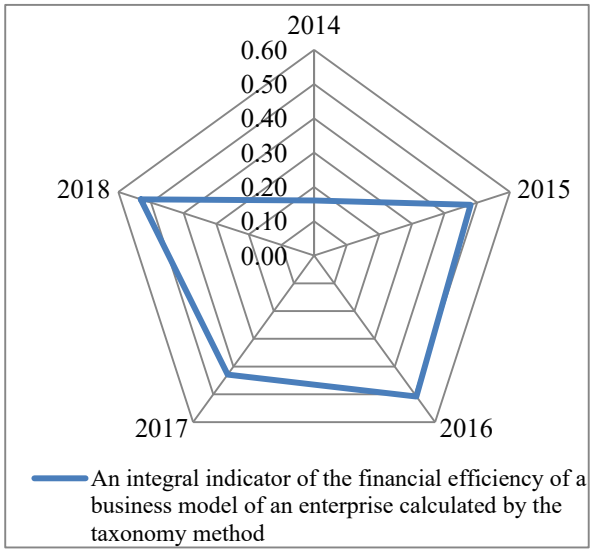

Fig. 3. The dynamics of the integral indicator of financial efficiency of a business model of an industrial enterprise calculated using the taxonomy method for 2014-2017.

Therefore, the interpretation of the calculated integral indicators of the financial performance of an industrial enterprise business model is as follows: it assumes high value at high values of stimulants and low value – at small values of stimulants (which clearly show us the results of calculations in Tables 6 and 7). The closer the index is to one, the higher the level of financial efficiency of the business model of the enterprise. An indicator of the financial performance level of an industrial enterprise's business model can serve as a statistical characteristic of many elements. It is possible to estimate the "average" level of the indicators that characterize the problem, achieved in some period of time.

The results of the study indicate that both methods of calculation indicate the same tendency of change of integral index of financial efficiency of business model of industrial enterprise and confirm the possibility of application of Harrington function and taxonomic analysis in construction of integral index of financial efficiency of business model of industrial enterprise that fully reflects the adequacy of the operation of an industrial enterprise under the influence of various factors.

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Model of brand value management as a process of strategic increase of enterprise value

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Abstract. Constantly increasing the level of competition requires manufacturers of goods and services to individualize their products. Considering this factor, the brand takes on a new level of perception, a level of the strategic asset of the company, which allows evaluating the value of the company. With the pursuit of competitiveness and modernity, domestic companies have only in the last few years begun to view the brand as an integral part of their business, capable of generating additional profits at the expense of increased consumer loyalty. However, there are currently no standard methods for evaluating brand value, and there are some disadvantages to applying them. The article deals with modern research methods of the Interbrand and V-RATIO brand. It is revealed that the results of the calculations by different methods differ depending on the set goal: long-term or short-term costs. 19 brand evaluation criteria are considered. We propose our conceptual model of brand value estimation based on a closed system of factor analysis and modeling. The impact of the criteria on the choice of alternatives for choosing brand value strategies is suggested to be found by the Saati hierarchy analysis method. To enhance the adaptive properties of the selected criteria, it is proposed to use the mechanism of alternative strategies for increasing brand value by incorporating the Kohonen neural network process algorithm. The structure of hierarchies of influence of defined criteria on the brand development scenarios was constructed. Calculations were made by the method of analysis of hierarchies in the author's developed system, and it was found that having the resources to increase only one criterion of brand development would be the best development of leadership or internationality of the company. Based on the calculations neural network in the MATLAB, it was found that enterprise, which was researched, needed to pay attention to advertising costs or to increase brand value.

1 Introduction

Today's economy is changing rapidly, so the impact of the brand on value added can sometimes play not just an important but also a fundamental role. Because of this fact, every modern enterprise that wants to be competitive in the market should have a strategy to develop its brand. Brand development can be done for different purposes: to increase value added, to sell, to the franchise, etc. For each goal, you can choose a specific development method and apply it to the desired values, but sometimes it is very difficult to determine the purpose, evaluation criteria and overall object of evaluation to obtain the desired result.

There are many different studies around the world to study brand valuation methods, but none of them has become a benchmark. This problem is very relevant for Ukrainian enterprises because the interest of domestic entrepreneurs in the study of brand value is minimal. If large business executives are thinking about brand development, then small and medium-sized business representatives are not sufficiently aware of the potential benefits of brand implementation.

It is especially difficult to estimate brand value because of uncertainty about the concept of "brand", as well as the many factors that affect its value due to lack of standards. For example, D. Shevchenko, wrote [1]: "A brand is a sign, symbol, words or their combination, phrases that identify and help consumers distinguish goods, services, companies from competitors". Instead, J. Gregory, founder of the consulting firm CoreBrand, described the brand as the sum total of a person's experience, perception of things, products, company or organization. A brand is not the thing itself, not the product itself, not the company or organization itself. Brands do not exist in the real world – they are mental constructions. Brands exist in the form of consciousness or of specific people or society [2]. In turn, D. Ogilvy, founder of Advertising Agencies, made the following definition of a brand: "A brand is an elusive sum of the properties of a product: its name, packaging and price, its history, reputation, and advertising style. A brand is also a combination of the impression it makes on consumers and the result of their experience in using the brand" [3]. Peter Doyle, consultant for Coca-Cola, Shell, IBM, gave the following definition of branding [4]: "A brand is an aggregate that consists of both a product that

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satisfies the functional needs of consumers and an added worth that drives consumers to feel more satisfied with by forming a belief that this brand is of a higher quality or more desirable to them than similar brands offered by competitors". Thus, authors of different models and techniques interpret the concept of "brand" in their sole discretion. In this regard, many studies have some uncertainties in the application of the techniques and the number of such works increases over time. Based on the definitions of other authors and the specific task, we will give our own definition of brand. If you delve into the etymology of the concept, you can understand that the brand meant "stigma". So, we will perceive the brand as a set of design decisions, advertising photos and video works, planned interactions with the consumer, which aims to build the reputation of the company, leaving the "stigma". The article [5] states that there are two levels of brand value: current and appropriable. For each business, these parameters may vary, as they are subjective parameters that depend on the resources and capabilities of the target audience. The current level of value is based on projected profit, and the appropriable level can be obtained by the company provided the effective use of available brand equity.

There are two international standards of brand assessment. The first ISO 10668:2010 "Brand valuation – Requirements for monetary brand valuation" was developed and approved in 2010 [6]. The 2010 standard establishes that when evaluating brand value, three aspects must be considered: financial, behavioral and legal. The legal aspect should include a clear definition of the concept of "brand" and the intellectual property law that is associated with it. The behavioral aspect includes an analysis of the behavior of all participants in business processes in the geographical, product and consumer segments of the market if there is a brand. The financial aspect considers three alternative approaches to assessing brand value: income, market, and cost. Estimating brand value using an income approach examines the brand life cycle and the economic effect that can be obtained from the brand in the future. With this approach, the net present value is calculated; it includes the amount of future discounted net profit flows that will be received when using the brand, that is, the cash flow difference in the presence and absence of the brand. The market approach is based on determining the expected price at which the brand can be sold in the free market. With this approach, similar brands are selected that are comparable in terms of brand strength and market position of goods and services. The cost approach can be used to calculate the minimum indicator of brand value, it consists in determining the amount to invest in creating and developing a brand for a non-brand product to achieve the same market position as the brand being evaluated. The second standard ISO 20671:2019 – "Brand evaluation – Principles and fundamentals" contains technical requirements and methods that are used to evaluate a brand; also he forms a holistic approach to brand valuation, which includes the non-financial and financial aspects of valuation, and is a benchmark for the development and implementation of other brand evaluation and brand valuation standards [7].

Among the many modern techniques used in practice are the following: Interbrand [8], V-RATIO [9], FutureBrand [10], BBDO Consulting [11], BrandFinance [12], Damodaran's Model [13], Consor [14] and other.

The results of studies of these methods vary greatly depending on the goal, as well as internal and external conditions. For example, if a company work for a long-term perspective and at the moment sales are low or are falling and profitability is negative, then the Interbrand method is valued at a low level, while the V-RATIO method considers long-term prospects, which significantly changes the conclusions.

Scott M. Davis developed 19 different criteria for brand assessment [15]. Each of the criteria is optional and different companies choose the most relevant criteria for evaluating their brand. Based on the analysis of the frequency of use of certain criteria, eight benchmarks were eventually selected, which were named ROBI 8 (Return on Brand Investment) [15].

Consider 19 criteria developed by Scott M. Davis:

1. Recognition that is the ability of the consumer to remember the brand and distinguish it from competitors.
2. Understanding the brand position, that is, the degree of consumer understanding of the organization's position and the essence that it wants to convey to the target audience while introducing the brand.
3. Fulfillment of obligations implies compliance of the brand with the expectations of consumers and the fulfillment of the promises made to them.
4. Brand identity is rated as the degree of brand uniqueness, its constituents, compared to its competitors.
5. The level of associations involves the definition of criteria that allow you to evaluate the positioning of the brand and the vector of its action on the pyramid of values.
6. The number of consumers attracted by the brand.
7. The number of lost buyers, that is, the number of consumers who have abandoned the products of a given brand to the side of competitors or, in general, to purchase products in the industry.
8. Market share is the ratio of the number of consumers who use the brand's products to the total number of potential consumers.
9. Current market penetration is estimated as the number of additional goods and services that can be sold to actual buyers due to the strength of the brand of the company.
10. Buyers' loyalty to the brand's products and the amount of time they consume the brand's products.
11. The degree of influence of the brand of the company on the frequency of purchases of goods of the selected category.
12. The public interest is determined by the number of positive reviews in the Media, social networks about the brand.
13. Respect for a brand is the opinion of consumers about it and how they describe it in conversations with other people.

14. Indicator of recommendations is the percentage of new purchases made through recommendations from another buyer.

15. Customer satisfaction is an assessment of the degree of customer satisfaction with contact with a branded product or service.

16. Financial value is the market value of a brand in monetary terms.

17. The price premium is defined as the most permissible percentage of the price of a particular brand's goods in comparison with the products of competing brands.

18. Advertising profitability is the financial return on advertising costs.

19. Buyer's trust value. The buyer's trust parameter shows how important it is to maintain brand loyalty in buyers, and how it will affect other brand advocates.

The qualitative characteristics of ROBI 8 include the following [15]:

1. Brand Awareness. To obtain results by this criterion, surveys are conducted similar to those conducted by advertising campaigns to obtain the results of their activities. Respondents are asked about the brand and are tested for both complete and comprehensive results with both answer options and open-ended questions.

2. Understanding brand position. Surveys among consumers who use products or abandon a given brand, which clarifies the consumer's opinion on the positioning of the brand. Brand positioning should be in line with the view of the target audience.

3. Criteria that indicate an individual brand identity, often coinciding with strong brand features. Most often, the brand identity that the company management sees does not match the opinion of the target audience.

4. Brand commitment. How far brand positioning and the promises made to them correspond to the real state of brand engagement with the consumer.

Based on the interaction of the consumer and the brand, the consumer forms his image regarding the expectations of the brand. It is very important that the promises made by the brand meet the expectations of the consumer to meet his needs, it should be noted that a strong brand always meets the expectations of consumers and creates loyalty, which is confirmed by a high level of sales.

The quantitative characteristics of ROBI 8 include the following [15]:

1. The number of buyers attracted by the brand is calculated as the difference between the number of consumers at the moment and the number of consumers before the introduction of the brand. The criterion should be based on the reasons for the purchase of the product, namely to take into account the consumers who have purchased the product through the actions of the company aimed at the interaction of the brand with the consumer.

2. The role of the brand in shaping consumer loyalty. This criterion is estimated by the number of consumers who have refused or purchased the product through the brand. The difficulty of obtaining the results of this criterion is based on the fact that a consumer survey is probable.

3. Frequency of brand purchases. The criterion describes the number of consumers who have increased their brand value purchases through a quality brand engagement strategy with the consumer. Under this brand, the company can market other products, while high loyalty of the main product will positively affect the loyalty to new products.

4. Brand value in financial terms. This criterion evaluates the value that a brand can add to a product, without losing regular customers because of too high a price and not seem low quality to new consumers because of low cost. This criterion is evaluated against competitors.

2 The basic results of research

The company in the field of brand evaluation Interbrand has developed its method, which is to determine the brand multiplier by 7 criteria, the combination of which defines "Brand Strength" [12]. On the basis of expert evaluation, each of the criteria is given a certain weight, and the calculated weights influence the further construction of the S-shaped curve, but the equation of the curve is not publicly available and is the intellectual property of the company Interbrand [8].

Based on the above mentioned methodology, we propose our own conceptual model of brand value estimation (Fig. 1). The main idea behind the concept is to develop a closed system of analysis and modeling of factors that affect the reliability of the brand value and its value in obtaining the company economic value. In this case, to enhance the adaptive properties of the selected criteria, the mechanism of their action to choose alternative strategies for increasing brand value by implementing the neural network process algorithm is applied. The neural network is a factor in approximating brand value estimates to actual market conditions and serves as a backbone to clarify the input associated with the criteria for influencing factors on the brand.

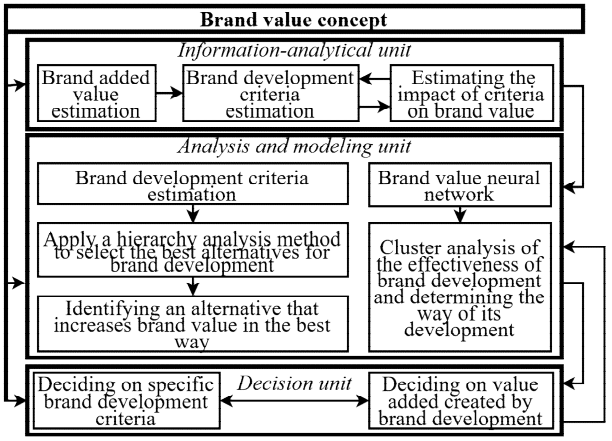

Fig. 1. The concept of evaluation brand value.

The concept, first of all, defines the basic approaches to the model of brand formation, criteria for its

evaluation. Once the evaluation criteria have been identified and their social significance established, the analytic hierarchy process (AHP) is applied to form a better alternative to development. The Interbrand methodology takes into account many criteria, in this case, the AHP can be applied, because the values are accurate and digital, and the priority of each of them is known. According to the AHP method, local vectors of *Wr* priorities are the solution of the equation [16]:

$$(Vr - \lambda * Er)Wr = 0, \quad (1)$$

where *Er* is a single matrix of corresponding dimension, λ is the proper number of the matrix of pairwise comparisons *Vr*.

In the next stage, in the process of establishing the effectiveness of brand development, Kohonen neural networks are used, and the results of the analysis provide recommendations for management decisions on brand development.

The development of information technology provides an opportunity to explore various economic processes under uncertainty. In particular, to achieve the goal of this research we use specialized software product MATLAB [17], aimed at helping the user with fuzzy logic, which analyzes object of research, based on the knowledge of experts, and helps to formalize linguistic data descriptions and to justify management decisions.

Many studies in the introduction of fuzzy technology in brand management made by O. Shtovba. In particular, the article [18] provides an overview of the use of fuzzy inference to solve brand management problems, such as: modeling brand product competitiveness; optimal management of the competitiveness of the branded product with cost; determining the level of formation of the consumer capital of the enterprise, taking into account its brand; determining the feasibility of brand extension; setting the price of a new brand product; determining the similarity of two verbal trademarks; evaluating brand viral spread on social networks.

Based on the analysis of different brand assessment techniques, it is a significant advantage to be able to develop a system for managing analysis and decision-making processes. But it should be noted that the primary reason for the bias of the primary data lies in the collection and processing of these data by experts, due to subjectivity peer review. In turn, the V-RATIO method is almost independent of expert opinion, but the scope of this method is quite specialized and requires a lot of input to analyze the brand of the company.

NVIDIA Corporation, a computer parts manufacturer, was selected to develop a brand value model using the V-RATIO method [19]. The purpose of the study is to simulate brand management situations to strengthen it in the market and increase its value. Three alternatives were used for the study, each of which offered different percentages that determined the share of the profit generated by the brand itself: the first variant – 14%; the second option is 39%; the third option is 71%. Thus, by calculating the sales generated by the brand; adjusted operating profit, and considering brand promotion costs, the free cash flow generated only by the brand (BFS) and the brand price (ads) were calculated (see Table 1). It was taken into account that the discount rate for the brand "NVIDIA Corporation" is 10.5%. As a result of calculations by the method of V-RATIO revealed: an increase in the percentage of profit generated by the brand, leads to a stronger position of the brand in the market.

Table 1. Discounted cash flows are created only by the brand.

Year	Variant	Indicator	
		BFS, $ million	ads, $ million
2019	Variant 1	3.71	3.54
	Variant 2	28.81	27.44
	Variant 3	95.49	90.95
2020	Variant 1	3.64	2.71
	Variant 2	28.24	20.99
	Variant 3	93.58	69.58
2021	Variant 1	3.57	2.30
	Variant 2	27.67	17.85
	Variant 3	91.71	59.17
2022	Variant 1	3.49	2.06
	Variant 2	27.12	15.95
	Variant 3	89.88	52.87
2023	Variant 1	3.42	1.8
	Variant 2	26.58	13.99
	Variant 3	88.08	46.36

However, the result made it possible to make sure that the profit share generated by the brand did not directly affect the result. A graph showing the dependence of a brand's revenue share on the brand value, if the share is between 1 percent and 100 percent, is shown in Fig. 2.

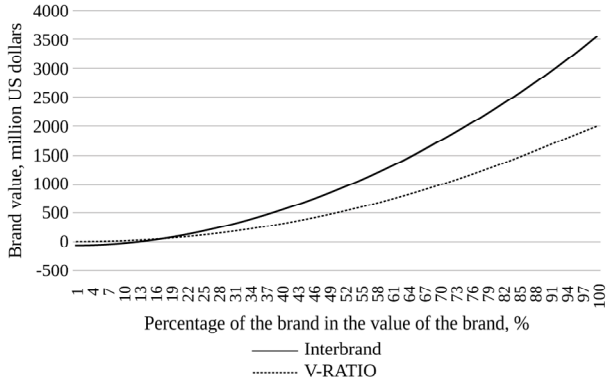

Fig. 2. Dependence of the share of revenue received by the NVIDIA Corporation brand in the value of the brand itself using the V-RATIO and Interbrand methods.

The V-RATIO brand value calculation method allows you to find out the intrinsic future value of a brand, to identify its strengths and weaknesses within the company, but it does not allow you to calculate the real market current value of the brand when it is sold. The Interbrand method was used to calculate the current market value of the NVIDIA Corporation brand, taking into account the following brand multiplier points (see Table 2). In order to compare the future intrinsic value of the brand with the current market value, the graphs are analyzed, showing the dependence of the share of the

revenue received by the brand on the value of the brand itself (Fig. 2).

Table 2. Points of brand multiplier.

Indicator	Maximum	Points
Leadership	25	22
Stability	15	13
Market attractiveness	10	10
Internationality	25	23
Trends	10	7
Support	10	9
Protection	5	4
Together		88

Thus, the market value begins to exceed the internal at the share of influence of the brand on profit more than 17%. After analyzing all the criteria that affect the value of the brand, it is concluded that if one or more criteria of the brand multiplier are increased, the additional value may not increase for various reasons, but the value of the brand itself will increase. Therefore, business leaders should make decisions regarding the development of brand criteria and focus on the most important for the enterprise.

To analyze the impact of different criteria on decision making, we apply the Saati hierarchy method of analysis. We construct the structure of hierarchies of influence of certain criteria on the scenarios of brand development of the company, Fig. 3.

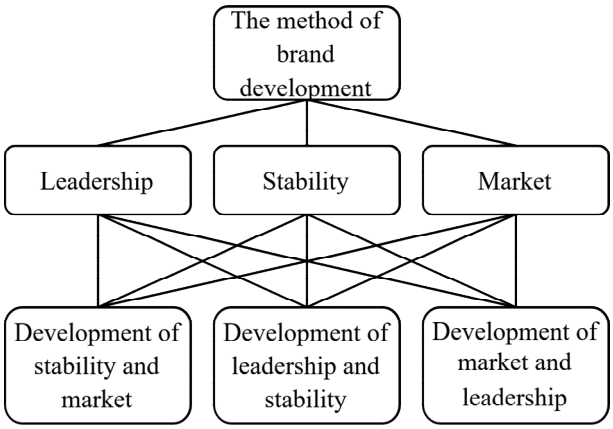

Fig. 3. The structure of the hierarchy of influence of certain criteria on the scenarios of brand development of the company.

In the case study, the number of criteria is quite large, but in practice, the number of criteria can still increase, which will complicate the task, so a system of automatic calculation in JavaScript scripting language was developed. The system is available at http://ahp.palemiya.com.

It is possible to add/remove criteria and alternatives in the system, as well as set criteria values. The system independently calculates a large number of alternatives and criteria that can be analyzed.

Calculations were made using the methodology of hierarchy analysis in the developed systems and it was found that having the resources to increase only one brand development criterion by one point, the best way to use the resources would be to develop leadership or internationality of the company (see Table 3).

Table 3. Results for each alternative.

Alternatives	Result
Leadership development	0.1425
Stability development	0.1415
Development of market attractiveness	0.14
Development of internationality	0.1425
Trend development	0.142
Support development	0.142
Leadership development	0.1415

Another step in evaluating brand value is to use reasonably selected parameters that, in fact, shape its value. To do this, we apply the Kohonen neural network to three input parameters that affect Intebrand brand value, namely: Brand value added, Multiplier, Advertising costs.

NVIDIA Corporation's brand value is known to be worth $ 26.5 million, or $ 2.65 billion. We leave the multiplier in its original form. Advertising costs will be presented in the same way as brand value added.

The "news" function creates a layer in the neural network: network = newsom([0 2; 0 1], [5 6]). For training in the Kohonen neural network, Fig. 4, we create an array with data corresponding to the added value of the brand, the multiplier and the cost of advertising:

P= [1.1 2.3 2.2 3.1 3.8 4.7 5.1 6.3 6.2 7.1 7.8 9.7; 0 3 4 10 10 12 14 15 15 19 17 18; 1.1 1.3 1.2 2.1 2.8 2.7 2.1 3.3 4.2 4.1 4.8 5.7]

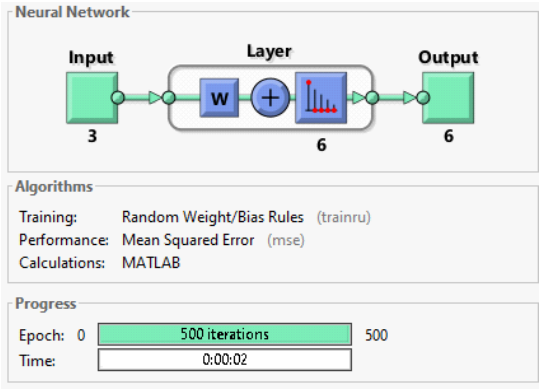

Fig. 4. Kohonen neural network.

Performing the necessary calculations in MATLAB software, we obtain an array of vectors (Fig. 5).

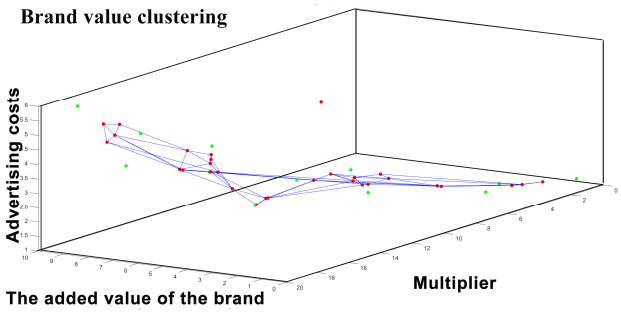

Fig. 5. Clustering the ratio of metrics that affect brand value.

Thus, the first three input vectors belong to the first cluster, vectors 4 and 5 refer to the 3 cluster, vectors 6.7 to 4 cluster, vectors 8 and 9 refer to the 6 cluster, and vectors 10 and 100 refer to the 5 cluster. If you create a vector with NVIDIA Corporation data, we get a result that matches the vector's membership to the 6 cluster NvidiaCompanyClaster = sim(net,[2.6; 19; 0.4]).

Based on this, the company needs to pay attention to advertising costs or increase value added through the brand. Multiplier indicators are balanced, but the cluster to which NVIDIA Corporation was assigned stands out for its high brand value, significant multiplier, and in contrast to cluster 5, high advertising costs.

3 Conclusions

The methodology that determines brand value is based on a system that uses neural networks with elements of artificial intelligence. In turn, it allows a completely different look at the process of modeling, which improves financial performance, increases the effectiveness of management decisions. An expert system-based brand assessment methodology applies to market relations, is easy to use, and eliminates any factors that should be subjectively evaluated by an expert. Since it is versatile in application, it can be used in any sector of the economy, any area of the enterprise. The results of the new methodology calculations provide data that is useful for analyzing and making brand development decisions.

But a significant increase in the value of a brand at the current time is possible if we apply different methodological approaches to its evaluation and model different scenarios of brand development. However, using one methodology, one cannot be sure that the results of another methodology will produce a positive result. If the essence of the brand is determined and the criteria for evaluating its value are well-established, then the campaigns should have an expert system with artificial intelligence elements. In the presence of big data, the expert system makes calculations in real-time. The advantages of the expert system are obvious and their application in the field of branding has considerable prospects.

The proposed approach to assessing brand value using the new methodology makes it useful to analyze and make brand development decisions.

The use of powerful computing systems for peer review leads to the conclusion that artificial intelligence can track the dynamics of changes in this process in real-time.

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FinTech as an innovation challenge: from big data to sustainable development

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Abstract. Driving force of human society development is elimination contradiction between unlimited usage of natural resources during economic activity of enterprises, environment pollution as a result of such activity and limited natural, energy and other resources. Research results on economic and environmental issues of green business management showed that there are several basic types of problems at present which arise at enterprises during collecting and processing data on the results of their activities. The authors analyzed how public sector and green business is catching up on global trend towards broader use of the big data analysis to serve public interests and increase efficiency of business activities. In order to detect current approach to big data analysis in public and private sectors authors conduct interviews with stakeholders. The paper concludes with the analysis what changes in approaches to the big data analysis in public and private sectors have to be made in order to comply with the global trends in greening the economy. Application of FinTech, methods of processing large data sets and tools for implementing the principles of greening the economy will enable to increase the investment attractiveness of green business and will simplify the interaction between the state and enterprises.

1 Introduction

In modern conditions of socio-economic development, leadership in the world markets belongs to the countries whose economic development is dominated by innovation activity. There is always a demand for green innovations, so they are and should be a priority in the policy of any country that is constantly striving for economic development. In most developed countries, the regulation of innovation activity takes place through different levels of government participation. At that, the key role in the processes of innovation activity is given to the subjects of entrepreneurship (transnational corporations, representatives of large, medium and small businesses).

At present, it is possible to highlight the main directions of stimulation of innovative activity of developed countries: implementation of large and perspective target projects in sustainable development that cover all stages of the scientific and production cycle, usually with a significant part of scientific and innovative potential, creation of a favourable innovation environment, development of green innovations through the development of innovation infrastructure, sensitive to the achievements of world scientific and technological progress, coordination and interaction of various economic sectors in the field of science, environment and technology, distribution of green innovations.

Governments worldwide accumulate wide range of datasets containing information about different processes involving many actors. Recently it has become evident that new instruments of big data analysis could put unstructured datasets to use. Possibilities to use large datasets are considered in both private and public sector. Private businesses use big data to increase profits whereas government is interested in more efficient policymaking and realization of sustainable development principles.

Incorporating fragmented datasets collected by different agencies especially when they become available to the public facilitate achievement of goals of the public sector, private sector and civil society. On the other hand there are many factors that limit feasibility of substantial increase in utilization of big data analysis in decision-making process in nearest future: high cost of technical solutions, fragmentation of datasets and complexity of data-sharing between different agencies, lack of expertise in big data analysis among public servants, low level of data security etc.

2 Research results

2.1 Sustainable development trends and challenges

Investment into natural environment protection is an important component of state ecological and economic policy in countries around the world. According to research of International Organization REN 21 [1, 2], amount of green investments in 2004 was 47.0 billion dollars and by the end of 2015 it was 312.2 billion dollars that is 6 times more than in 2004. Then there was a slight reduction of investments into renewable sources, however

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by the end of 2017 the amount increased and reached 241.6 billion dollars.

Slight reduction of green investment, first of all, caused by cutting down financing of alternative sources projects development (solar power, thermal and hydropower, biofuels), switching and using more such traditional sources as nuclear energy. Projects on improving energy efficiency for existing technologies and installations become more popular.

The largest volume of green investments directed into implementation measures of environment protection accrue to (Fig. 1): China – 78,3 billion dollars, United States of America – 46,4 billion dollars, Great Britain – 24,0 billion dollars, Japan –14,4 billion dollars, Germany – 13,2 billion dollars, India – 9,7 billion dollars, Brasilia – 6,8 billion dollars, Australia – 3,3 billion dollars, Belgium – 2,9 billion dollars, France – 2,6 billion dollars. Instruments of green economy are used in these countries not only at level of state regulations in terms of developing green strategies and measures for its implementation but also at level of enterprises during formation of environmental management systems and management decision making.

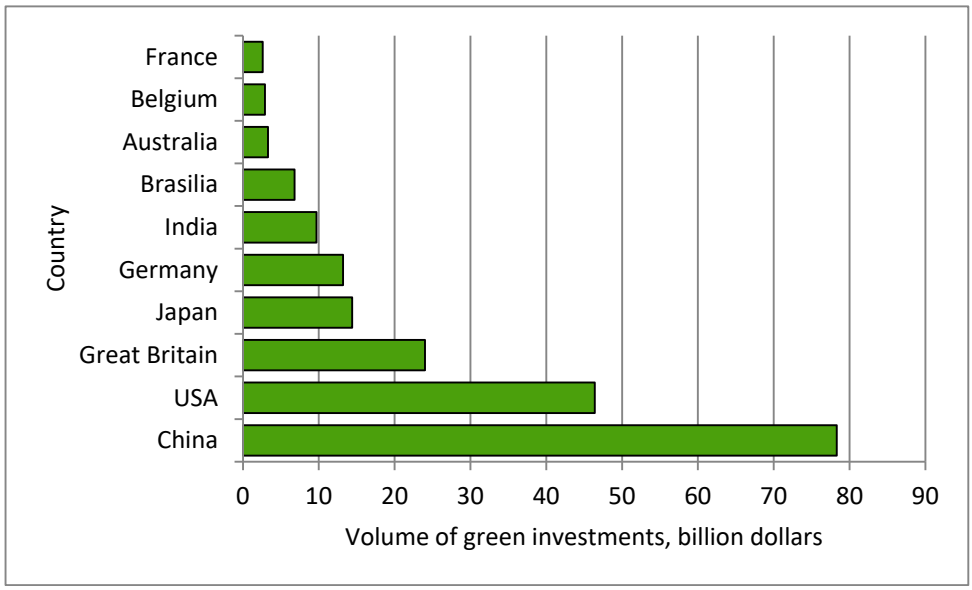

Fig. 1. Green investments directed into implementation measures of environment protection in 2017.

At present, green energy sources come up to 19% of global electricity consumption. The largest producers of green energy sources were such countries as: China, USA, Great Britain, Japan and Germany. Despite a number of problems related to reduction support of development of the sector at legislative level and deterioration in the business environment in many countries in the world, the sector of economy continues developing. Significant development is observed at energy industry where the amount of produced energy resources increased more than 8 %. Sales in hydropower sector increased by 4 %, other renewable resources – almost by 17%. Along with other renewables sales of solar and wind power declined. The reason is that it is more expensive way to produce electricity compared to alternative energy sources; first of all it is connected to weather conditions and production downtime. Therefore, a large number of wind and solar power construction projects remain without government financial support.

Unlike previous types of alternative energy sources, usage of biofuels increased significantly. It is related to both gaseous biofuels (mainly biogas) and development of hybrid versions as biodiesel – natural gas for busses and electric diesel vehicles. Using biofuels is highly profitable in many countries in the world because these resources are renewable in comparison to natural resources (oil, gas, coal etc.). Besides, increasing demand for biofuel leads to expanding of renewable sources market and provides creating additional workplaces.

Renewable energy is one of the most promising types of economic activity in a green economy. For many years hydropower has been predominant among the world's renewable energy production units, producing more than 50% of the total production capacity. In 2017, hydropower production was 1096.0 GW, or 54.36%. Among other types of green energy the leading place is given to the following types: wind energy – 487.0 GW or 24.2%, solar energy produced by photovoltaic methods - 303.0 GW or 15.0%, bioenergy – 112.0 GW or 5.6%, geothermal energy – 13.5 GW or 0.7%, solar energy produced by concentrating type systems – 4.8 GW or 0.2% (Fig. 2).

Over the past ten years, the economic sector has grown enormously. In fact, about 80.0% of natural resources were used to produce electricity. Despite that fact that investments into projects for production of solar cell batteries were reduced, modernization of the sector was done; thereby, power of such batteries was increased by 32%. Such renewable energy sources as solar energy, wind and heat are used widely. For example, EU countries switch to using wind energy more and more. In Denmark the figure is 33.2% of total produced electricity, in Spain – 20.9%. At the same time, Italy reduced consumption of other types of energy by 7.8% due to solar energy.

Governments and representatives of green businesses are increasingly using FinTech and big data analysis to serve public interests and increase efficiency of business activities. The use of modern methods of data processing and analysis allows predicting trends in the development of the world economy, the situation on international markets, to determine the directions of economic and environmental policies of different countries, and for green businesses not to lose profitability and increase the efficiency of activity.

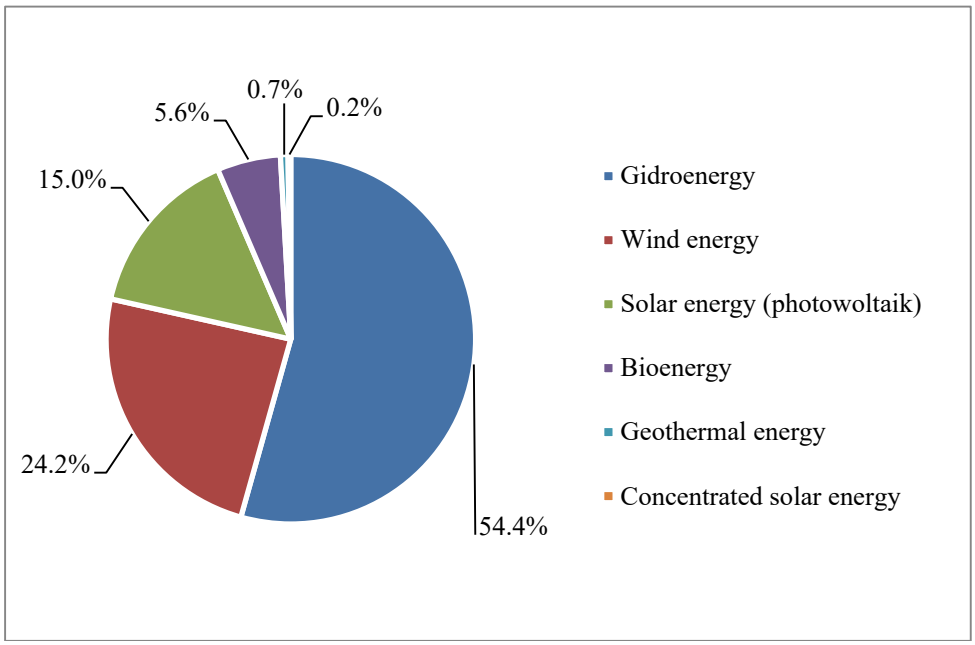

Fig. 2. Structure of renewable energy sources in 2017, %.

2.2 Big data role in FinTech development

The financial support system for innovation activity in the field of green business is derived from geopolitical, socio-political and macroeconomic processes. The overall cost of innovation can include the enterprise's costs to innovate something new in the field of green technologies both to the enterprise and to the market, including internal research, acquisition of R&D products, machinery, equipment and software, any external knowledge, and other expenses.

The only problem with the use of financial technologies in the field of green business is that market mechanisms are not able to attract investment in green projects. This is due to the high riskiness of the projects and the long payback period. Therefore, government support plays a big role in green business. In such circumstances, FinTech and their instruments play a significant role in attracting green investments as they are able to justify their economic and social effectiveness.

Digitalization increasingly influences both public institutions and green business entities. FinTech will eventually become essential in decision-making process in both public and private sector, even though FinTech initiatives and infrastructure develop more rapidly in private sector. Ability to use big data analysis as a tool of FinTech development is an important competitive advantage in modern green markets.

Regression analysis can be one of tools for the green investment analysis. The following model (1), developed by I. Rakov [8] on the basis of research by H. Akaike [9] and G. Schwarz [10], allows evaluating the effectiveness of state support in attracting investments in the field of green business:

$$y_t = \alpha + \beta_1(L^i)x_{1,t} + \beta_2(L^j)x_{2,t} + \beta_3(L^p)x_{3,t} + \varepsilon_t \quad (1)$$

The dependent variable y_t is the amount of green investment per year. The independent variable $x_{1,t}$ is an amount of government spending on environmental protection and the independent variable $x_{2,t}$ is an indicator of the effectiveness of the state's environmental policy. World GDP is an external factor $x_{3,t}$ which is effects on the country's economic development and investment attractiveness. The time lags L^i, L^j, L^p are estimated to be one year and ε_t is an error term [8].

Such a model is appropriate in economic, environmental and social terms and deserves attention. As can be seen from this model, it requires analysis of a large number of macroeconomic indicators, and this is only possible with the use of big data analysis and the involvement of FinTech.

Boyd and Crawford [3] underline complicated process of analyzing big data as its distinctive characteristics. Big data is related to business intelligence and market analytics. Developing tools for making effective decisions based on analyzing big data on green business activity is becoming an increasingly important issue for practice. Data becomes cheaper and more accessible, but analysis makes it important and valuable in decision making. The emergence of e-documenting initiatives and enterprise environmental reporting is closely linked to the challenges of new approaches to big data analysis in the public sector and the private sector involved in green business.

Crawford [4] draws attention to existence of the potential of biased approach towards big data analysis depending on agenda. Quantitative analysis can be refining with qualitative research, but in this case more sophisticated methods have to be used. Public Sector institutions generate, collect and store many different datasets that are effectively big data, but in majority of cases green business decision-making process does not involve big-data analysis. Limits and potential of the big data analysis are defined by the existing ways of collecting and storage of the datasets, existing infrastructure, and experience in green entrepreneurship, alternative energy, green production, and more.

As noted by K. Desouza and B. Jacob [5] big data initiatives have emerged on different levels of the governments of the advanced economies. Big data on green economy development can be distinguished from ordinary data by four main factors: volume, speed, variety and complexity. Big data is a big data set on green market development, sales volume, new market players, built quickly. Particularly important is the fact that such data is composed of different elements and is largely unstructured.

G. Kim, S. Trimi and J. Chung [6] provide comparison of the private and public sector in terms of potential usefulness of analysis of the big data, the main goals (profit-making for green business entities and public goods provision for the public sector) as well as timeframe of the impact (short-term for green business entities and long-term (strategic) for public sector).

J. Mervis [7] emphasizes substantial efforts that governmental agencies put into improving ability to utilize big data in process of implementation of the green strategy. Governments of the developing countries are following global trend in sustainability and explore potential options to use big data analysis in public sector in order to increase efficiency of the decision-making process. Lack of tools to quantify the efficiency of public spending on the big data analysis is one of the problems faced by the governments that can limit financing of the projects in the field of greening.

In practice, FinTech is a startup project that implements modern financial technologies and makes financial services more efficient. However, the cost of implementing and servicing such projects is reduced. The implementation of such projects entails a reduction in the banks' aggregate profits, overdraft revenues and the cost of payment services. At the same time, the increased risk of liquidity loss increases as the customer becomes less dependent on a particular banking institution. In this context, the problem of effective management of the financial sector and implementation of effective policy by the national bank of the country is becoming increasingly important.

The policies of financial institutions at the state and regional levels should be aimed at investing in Fintech start-ups. They help banks reduce costs and provide customers with new services. The rapid development of the Ukrainian Fintech has been caused by the unstable economic situation in the country in the last 10 years. As a result, public access to banking services has decreased significantly and distrust of traditional financial institutions has increased.

As a result, many national initiatives were launched by the National Bank of Ukraine aimed at supporting the Fintech industry, including: adopting Ukraine's digital strategy, switching to digital circulation, authorizing the use of electrode signatures, implementing universal Bank ID and Mobile IDs.

The main purpose of Ukrainian Fintech today is money transfers and crediting. Other participants work in the fields of financial management, infrastructure, marketplaces, telecommunications, blockchain, media and others. Among the most relevant services are: alternative payment methods (payment terminals, contactless and mobile payments, QR payments, electronic and digital wallets), mobile phone services, financial services and social networking services, marketplaces, artificial intelligence, open APIs, digital and biometrics identification etc.

2.3 Big data for the public and private sectors in Ukraine

Rapid technological and social changes lead to dynamic changes in the economic environment and the loss of investment attractiveness of old business models, including in the financial sector. Investments in green models and projects are becoming increasingly relevant. Against this background, the strengthening of the financial stability of the banking system and its greening are becoming increasingly relevant and important.

The National Bank strives for financial sector regulation to stimulate economic development on a sustainable basis, taking into account environmental challenges and the needs of all actors involved. The National Bank's strategy identifies a number of managed activity priorities. The main instruments include: achieving low and stable inflation, ensuring the stability of the banking system, resuming lending and currency liberalization, adaptive regulation of the financial sector. Creating conditions for the development of new green Increasingly relevant is the creation of conditions for the development of new green financial instruments and business models that meet the requirements of international standards, alignment of national regulatory framework with international standards and EU legislation, transformation of the National Bank and greening the financial system as a whole. In this context, the use of running dates to respond quickly to rapid economic changes and justify the feasibility of environmental projects is becoming increasingly relevant.

Public sector agencies in Ukraine tend to collect data about their counterparts from the private sector every time it is possible, large portion of the data collected by them exists in paper format and cannot be reached by other public sector institutions. Datasets collected by public sector institutions in digital format are mainly unstructured and stored in separately in information systems of each agency. Thus, when private sector actors in Ukraine encounter different public sector agency, they

have to provide them with relevant data, even if these datasets have already been delivered to the other agency.

The green economy sector is no exception to these situations. The issue of securing personal data collected by different public sector agencies remains problematic, since IT-infrastructure is obsolete and lack of financial resources leads to fundamental fragility of the system.

Approaches to analysis of the big data in public sector in Ukraine use Estonian experience as a blueprint. Ukrainian IT-system for e-government "Trembita" (implemented in Ukraine since 2018) is an adaptation of the X-Road system. The main value of implementing "Trembita" in Ukraine is that all public sector bodies will have an opportunity to share data in real time. In case of successful implementation of the system, there will be no need to collect overlapping datasets and store it in databases.

Nowadays each public sector agency collects as much information about business as possible. This system is a key to reengineering of administering processes in the public sector, it will be the main tool for implementation of reforming variety of spheres, especially in the sphere of ecologization of enterprise activity. Interaction between governmental bodies, between public and private sector bodies are inefficient, heavily bureaucratized, resource-intensive. IT-based solutions in public sector will increase quality of processes in public and private sectors.

Open data (datasets available for free use and sharing) initiatives in public sector in Ukraine are implemented under "National anti-corruption strategy", realization of the policies in open data sphere is carried out by the State agency of electronic governance of Ukraine. The unified web-portal data.gov.ua provides open data from different actors of the public sector of Ukraine. The State agency of the electronic governance develops and implements strategic documents, recommendations concerning open data in public sector, ensures improvement of quality of datasets and their use. The Cabinet of Ministers of Ukraine defined the datasets that are obligatory to publish on data.gov.ua portal, these datasets are available for machine reading and subsequent analysis by public and private sector actors. The number of open data datasets published by public sector institutions in Ukraine is expected to reach 50000 by 2020 and government included stimulating development of projects based on open data analysis as one of priorities in it plan of actions until 2020.

Development of the big data analysis in public sector in Ukraine is within framework of implementing electronic democracy. Particularly important for big data analysis is creation of public-private partnership projects (mainly based on Open Data analysis). Green business in Ukraine needs a lot of support from the state, so creating a public-private partnership in this area is essential and important.

According to the Ukraine-EU association agreement, Ukrainian legislation has to be harmonized with "the highest European and international standards" in personal data protection. Thus, the Action Plan on implementation of the Ukraine-EU Association agreement contains implementation of GDPR (enacted in the EU on 25th of May 2018) that contains important regulations concerning modes of use of personal data.

For now, Ukraine is considered country with low level of safety of personal data, but implementation of GDPR in Ukrainian legislation is pending for now. According to information shared by those involved in preparation, the main features of GDPR will be implemented in Ukraine: consent to process personal data will be in more understandable format, possibility to withdraw previously given consent to process personal data will be guaranteed, users of personal data will be obliged to implement reliable mechanisms to secure personal data, – these changes will make Ukrainian legislation similar to the EU regulations.

Data governance and privacy concerns arise in connection with big data analysis in public and private sectors, since it is important to ensure secure storage of personal data and prevent illegal use of the datasets.

2.4 Big data analysis in financial sector

In order to identify what approaches towards big data analysis can be the most beneficial for sustainability and greening the economy of Ukraine we relied on information acquired from interviews with representatives of the National Bank of Ukraine. This public sector institution was chosen as an object of investigation of possible approach towards big data analysis in public sector in Ukraine because of several reasons. It is perceived by experts as one of the most modernized and independent institutions of the public sector in Ukraine, it has proven track record of capability to perform successful reforms of its internal processes and transfer of the experience both to other public sector institutions and commercial banks. The National Bank of Ukraine is responsible for the large part of drafting the strategy of economic development.

Central banks in many countries increasingly use big data to improve efficiency and strengthen supervisory functions in banking system, compliance assessment, macroeconomic analysis, increase relevance of decisions concerning monetary policy, green development, regulate transactions between different green business actors, carry out stress-testing at the enterprises.

The international practice of big data application in central banks worldwide was reviewed. Thus, a division with functions of methodological support of big data analysis was established. This division is expected to develop tools for inclusion of high-frequency alternative macroeconomic indicators, media indicators and elements of machine learning in process of data analysis.

Traditional approach towards data analysis in National Bank of Ukraine include collection of relatively small amounts of highly structured data acquired from historically reliable sources, coherent and clear model of data analysis is employed. On the other hand, data is entered and processed manually and it is quite time-consuming process, only official data is taken into consideration (which is a significant drawback in Ukraine, since shadow economy constitutes more than 35% of the economy).

At first it was important to make sense of the term "Big Data" as large datasets from traditional sources, but later it became evident that sources of the big data are broader. Thus, the need to broaden range of data available to refine results of the analysis of green sectors and green economy development have led the National Bank of Ukraine to explore possibilities to include big data analysis in decision making and economic analysis process.

Motivation to implement big data in the National Bank of Ukraine is in large part connected to the need to adopt more forward-looking approach towards economic analysis and prudential regulation, more efficient fraud prevention, combat corruption, improve compliance analysis, develop monetary policy. In order to draft a plan to implement big data analysis in National Bank of Ukraine the experience of central banks of the EU, Thailand, Indonesia, China, Japan, UK, India were compared in order to identify the areas of potential use of the big data.

Representatives of the National Bank of Ukraine perceive big data analysis as a tool to optimize processes of data collection (shift from manual and time-consuming processes to automated real-time monitoring, reporting and consolidated data collection), it is expected that specialized modern software will facilitate machine learning and supthech (supervisory technology) development. Quality of the standard data can be improved if unconventional sources of big data are included to refine datasets such as: web-sources, API-sources, social media etc.

The National Bank of Ukraine is already conducting web-scraping of some alternative macroeconomic indicators (such as index of sustainable development, international innovation index, consumer price index, unemployment rate etc.), uses application programming interface (API) to formulate alternative macro indicators. Training for employees to study Python programming language was carried out in order to have in-house competencies in web-scraping. It is planned to further develop competencies of the staff of the NBU in the field of big data analysis and work with both public and private sector actors to share datasets. The NBU has a plan to build modern big data analysis infrastructure until 2020 to be able to use web-search, social media, API, blockchain technology. In case existing initiatives in big data analysis in the NBU are implemented, it is expected that financial supervision will improve, monetary policy will be more relevant and decision-making process will become faster, cheaper and more efficient.

2.5 Modernization of economy on the basics of green growth

There is a demand to develop effective measures for ecologization under current complex economic and ecological conditions. It becomes possible by creating global model of green business development which is based on investments of state funds in profitable environmental projects and conservation of natural resources for future generations. Priority measures for economy ecologization should consists of: assessment of the natural services providing at international, national and regional levels; effective environmental policy; use of market mechanisms to implement of sustainable development concept; creating green workplaces.

The National Bank's decisions should be based on the following priority areas for structural reform: promoting innovation, improving infrastructure, developing competition and favorable conditions, improving and strengthening the financial system, promoting tax reform, enhancing environmental sustainability, promoting inclusive growth, promoting trade development and promoting trade , promoting labor market reform, educational attainment and skills. Big data issues are becoming increasingly important as an effective tool for efficient reallocation of resources.

In this context he uses of big data allows the company to gain tangible competitive advantages. Big data technologies can be useful for solving the following tasks: forecasting the current situation in the markets of eco-products and eco-services, marketing and optimization of sales of eco-products, decision-making and management in the environmental management system, improving productivity and creating green jobs, efficient logistics, monitoring of assets nature conservation purpose.

Green business development requires considerable cost and additional government support. That is why the tools of running date, analysis of big data sets, interpretation of trends and specifics of development, accent on popular industries are becoming very popular. The use of running dates allows to carry out a full analysis of the project implementation and to create the structure of investment portfolio for its implementation. This is where the help of Fintech tools come into play, which greatly simplifies financial transactions and interaction between companies in different countries. Financial technologies, websites and applications help minimize green business costs.

Today, FinTech in the green business is used for cash transactions, conclusion of insurance contracts, remote asset management of environmental purposes, storing funds in electronic wallets, paying for online services, obtaining loans for environmental projects without the help of banks.

The use of Fintech allows integrating green economy sectors with the financial sector. The development of technology will simplify many processes. For example, in agriculture, you can now use sensors or drones that record the state of crops and their growth dynamics, taking into account various factors. By collecting and analyzing these data, the bank receives a risk assessment for lending to agriculture, based on real statistics.

Development of energy complex, first of all, depends on GDP growth and development level of economy in general. It is necessary to consider approaches to forecast production and consumption of energy resources, which are presented by the energetic strategy. Though, such renewables as solar and wind power is developing rapidly in Ukraine, it is not enough for structural changes in energetic balance. There will remain constant trends towards using coal as the main energy resource in the country for another 20-30 years. This goes to prove

priority use of non-renewable natural sources. However, all economically developed countries and other countries in the world switch to alternative energy sources.

Along with development of alternative energy sources and reducing consumption of natural resources, there is also a problem of waste utilization as an integral part of green energetics process. Greening of Ukrainian economy may cardinally change image of Ukraine among other countries in the world and lead to further improvement of investment climate.

Use of effective methods and tools for implementing provisions of conception of greening economy will reduce amount of non-renewable natural resources, reduce costs for installation and use of alternative energy sources, ensure ecosystem restoration and ecological and economic growth of Ukraine in general.

Conclusions

There is a demand to develop effective measures for ecologization of all spheres of economic activity under current complex economic and ecological conditions. Implementation of principles of ecological economics becomes possible with using methods and mechanisms for its implementation, such as: price formation taking into account environmental factors; assessment of natural resources and loss of its overexploitation in money terms; ecological tax reform by increasing value of ecological taxes and reducing rates of other taxes and fees; target state policy of procurement on production and sales of ecologically clean products; increase state investments in development of renewable energy sources; construct treatment engineering and others. The existence of a large database of environmental processes in enterprises is often difficult to analyze. Therefore, there is a need to use financial technologies and methods to analyze large amounts of data, such as running date analysis.

Currently traditional data analysis is predominantly used for economic analysis in public and private sector. There is considerable potential for improved strategic planning at green enterprises, better understanding of the economic and ecological activity which is now not accounted for during traditional data analysis (shadow economy), shift to forward-looking approach to data analysis in the sphere of green business and green innovations. We detected several issues when it comes to implementation of the big data analysis in public and private sectors:

- modernization of the equipment, the choice of software compatible with existing IT-infrastructure would require significant investments as well as additional training for the staff;
- in order to facilitate implementation of the big data management in the sphere of green business it is necessary to create automated system of data sharing between public and private sectors;
- digitalization is largely dependent on support from donors (countries and organizations), this situation is unsustainable in the long-run;
- there is lack of skillful employees in area of green economy analysis;
- complexity of implementation of Fin Tech and big data analysis in the developing countries.

Review of the current state of the big data analysis have made it evident that there is growing understanding of possible benefits of use of this techniques in public sector, namely in decision making process, supervision, anti-corruption measure, fraud prevention. Eventually, existing issues that halt development of the big data analysis initiatives could be resolved and this might lead to exponential growth of such initiatives in public sector. Under these circumstances it is reasonable to combine economic and environmental component of social and economic reforms at national, regional and local levels and to consider it as a complex when looking for ways out of tough economic situation. Considering these, strategic model of sustainable development should be based on the following principles of green economy:

- assessment and priority to provide natural services at national and international levels;
- ensure employment of population by creating green workplaces and development effective and appropriate environmental policy;
- use of market mechanisms to implement concept of sustainable development.

Therefore, it is necessary to improve theoretical, methodological, organizational and practical principles of green business functioning. Contribution to the transition of the industry to the principles of the resource effective and clean production is the key task for the implementation of the stable development concept in different countries. Application of FinTech, methods of processing large data sets and tools for implementing the principles of greening the economy will enable to increase the investment attractiveness of green business and will simplify the interaction between the state and enterprises. This will facilitate development of environmental business, implementing model of environmentally-clean manufacturing at enterprises of green business, preserving and efficient use of resources, reducing destructive effects of industrial and human activities on environment, consolidation of researches on adaptation of green technologies.

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Competition and cooperation between fintech companies and traditional financial institutions

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Abstract. The modern world is changing rapidly under the influence of digital technologies. This also applies to the financial sector of the economy. Since the mid-2000s, new fintech companies have entered the market. These companies are using new technologies to improve existing and create new financial services. In the course of their development, the interests of new market entrants often overlap with those of traditional participants, mainly banks. Investigation of the relations between fintech companies and traditional financial institutions gives an opportunity to form an idea of the financial picture of the near future. The research of the relations between fintech companies and traditional financial institutions gives an opportunity to form an idea of the financial picture of the near future. The article considers both aspects of competition and aspects of possible cooperation between financial market participants in a digital economy. The results of the scientific research demonstrate that cooperation will prevail over the competition. Probably existing financial institutions will reformat their architecture and become digital ones at the core.

1 Introduction

The digital economy is changing all aspects of socio-economic life. Changes are happening fast, they are global in nature and ones have new opportunities, but ones also generate new risks. New technologies make financial services more accessible to the general public. But on the other hand, the number of available financial services and their complexity is increasing. New risks are generated, including new forms of financial fraud. The financial sector reflects the changes that are associated with digitalization very clearly, as manifested through the formation of new market entrants – fintech companies. There are relations between new and traditional financial market participants that are not simple. These relations may take the form of competition or cooperation. Fintech companies need to search for new niches and offer something that may interest demanding consumer in order to avoid competition from powerful banks. Such issues are important to society: competition must not be destructive, and the market must not be chaotic. Of course, the best form of relations is cooperation in which market participants will complement each other and society will benefit most.

2 The current state of the fintech industry in the world

A fintech company can be defined as a company that uses the latest digital technologies to improve its financial performance.

Fintech companies, as a separate phenomenon in the financial world, have begun to develop actively after the events of the global financial crisis of 2007-2009.

This was facilitated by sharp decline in confidence in traditional financial institutions and the rapid development of digital technologies. It was this period that the first digital currency bitcoin appeared. It is based on blockchain technology.

The fintech companies' formation, as a new sector of business, has led to interest from investors, but investment activity was uneven (Figure 1).

The peak of investment is observed in 2018, after a significant drop in 2017. According to the interim report [2] in the global fintech sector, the first half of 2019 is characterized by a downward trend at the end of the six months caused by a decrease in the number of large deals compared to 2018.

Funding in the global fintech market has been slower in the first half of 2019: 962 deals totaling $37.9 billion were recorded in the sector.

Private equity firms remain active. They initiated 35 deals worth $1.9 billion in the first half of the year. The largest deals from 2019 to the present date were major mergers, acquisitions and buybacks, including: buyout of Dun & Bradstreet company for $6.9 billion from the U.S.; buyout of Concardis company for $6 billion from Germany; buyout of eFront company for $1.3 billion from France. Other important deals are expected to be completed soon, including the Fidelity's acquisition of Worldpay ($43 billion), the Fiserv's acquisition of First Data by ($22 billion), and the merger of Global Payments with Total System Services ($21,5 billion). Merger operations certainly improve investment statistics but do not increase the segment.

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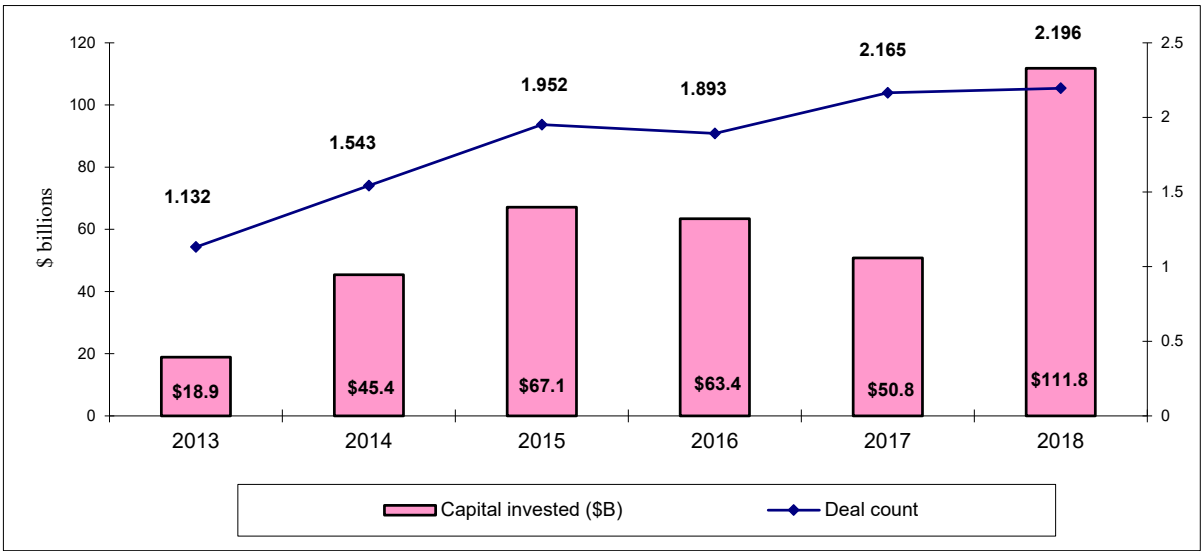

Fig. 1. Total investment activity (VC, PE and M&A) in fintech 2013-2018 [1].

In the first half of 2019, investment in the global fintech market slumped from $120 billion in 2018 to $37.9 billion as of mid-2019. Corporate venture investments, which reached an impressive $25.3 billion in 2018, plummeted to $4.75 billion in the first half of 2019. The main reason for this trend is that now corporations refrain from mega deals.

As in 2018, private equity companies' investments were insignificant due to low fintech market readiness and limited investment in industry leaders. Global private equity investments in the sector exceed $1.9 billion in the first half of the year.

From the beginning of the year, there was sharp drop in investment from $5 billion (which have generated 586 deals in 2018), to $1 billion (ones have brought 171 deals in the first half of 2019) in blockchain and cryptocurrency sector. Over the 6 months of 2019, investment in insurtech has sharply declined as a result of funding drop in the early stage.

Total insurtech investment fell from $ 7.6 billion in 2018 to $ 1.1 billion in the first half of 2019.

Fintech investment in Asia Pacific got off to a modest start in 2019 (only 102 deals worth $3.6 billion) after experiencing a record-shattering level of investment in 2018 [3].

The results of investment activity in 2019 can be explained by the following:

- investors are worried about the emergence of the global financial crisis in 2020-2021 and prefer liquidity over profitability;
- the leading companies in the fintech industry still have little their own funds to invest in development;
- the market is unstructured and products under development are often unclear to a wide range of investors;
- blockchain technology has not proven to be enough flexible to implement in many business processes;
- there were a lot of informational reports about failed projects in the field of fintech in 2018-2019. This can be illustrated by the example of the powerful Chinese Ping An Insurance Company. Chinese Ping An insurer has planned large-scale investments in various technologies, from artificial intelligence to blockchain, for the amount of $22 billion. The Ping An Insurance and Financial Group earns most of its money from the implementation of pension, savings, medical, and property insurance policies.

The group's technology development policy is investing in various startups. They will provide operational processes for the company.

There are a lot of projects and directions but not all of them are successful. For example, online health insurance provider called Good Doctor, which Ping An invested in 2018, is losing money. Autohome auto insurance provider, has lost about a quarter of its value since reaching its peak in May 2019. The Lufax capital management platform is having problems getting into an IPO. FinTech OneConnect has similar problems. A lot of money has invested in its activities too. Despite huge investments, Ping An's technology divisions have been accounted for only 3.8% of operating revenues, while implementation costs increased by 7% [4].

Insurers (except Chinese) are a lot less invested in technology than commercial banks. The insurance service has greater elasticity and often passive demand. Therefore, it is possible to automate insurance, to carrying it through mobile apps or with the robots' help only in certain directions (for example, On mandatory civil and legal liability insurance for motor vehicles owners).

The work of insurance mediators (agents and brokers) is required in voluntary insurance with flexible terms. Related insurance services will be transformed with new technologies. For example, programs like Audatex (preparation the cost estimates for repairing) or Auto Crash (assessment of cars which were damaged in a traffic incident), crash photo-, video simulation programs can virtually eliminate the institute's emergency commissariat. Programs are aimed at personalizing the insurance service and, accordingly, setting individual insurance rates can revolutionize insurance. These are telematics programs in auto insurance (Pay-As-You-Drive and Pay-How-You-Drive programs), risk assessment in personal insurance based on data analysis using Big Data. Future insurance is

a tariffs reduction through maximum personalization. But sales will depend on the work of agents and brokers.

There are also changes in the area of private investment. They are related to the emergence of robotics consultants who build an investment portfolio based on the client's risk attitude. Large investment companies often offer their clients the services of a robotics consultant as an additional and free of charge to ordinary brokerage services. Investors probably will be divided into those who prefer machine maintenance and those who will need human services. This will be in the plane of mentality, psychology and age qualification (Generation X will select people, and Generation Z will select robots).

Another important point needs to be addressed. A typical fintech startup is formed under a specific project. The result of the project may be new technology, an improvement in an existing technology or process. Often the result is the release of an application to perform a specific function. Taking into account the large number of fintech companies, often the global nature of their operations, the number and range of their services are large and varied. Often, consumers are unable to understand the functionality of the services or evaluate their usefulness for themselves. This trend is likely to continue in the near future. Instead, traditional financial institutions, such as banks or insurance companies, have operated for hundreds of years and are understandable to most consumers.

The fintech industry passport can be represented as follows (Table 1).

The banks are the largest fintech investors in developed countries. In the USA, the picture is as follows (Figure 2).

CEOs of the largest US banks see major protection against competition in investing in fintech companies. Banks are particularly interested in new payment technology, investment transactions and Big Data analysis. It is significant, blockchain technology has less interest in traditional banking institutions. Recently, in the expert environment, it is often thought that this technology is not well-developed for practical use in the field of finance.

3. Development trends of digital finance in Ukraine

According to the Ukrainian Fintech Association, Ukrainian banks not investing in fintech startups [8]. This distinguishes the Ukrainian financial market from the developed countries' markets of the world.

Today, two different models of financial services are being formed: traditional and technological. It should be noted that there is bound to be a competitive situation in at least some segments of the financial market.

The question arises: In which field competition between financial institutions will intensify and where fintech companies have a chance to gain an edge over traditional banks. A clear answer to the question is provided by the statistics of fintech investments (Figure 3).

Table 1. Fintech industry passport in 2019 [5, 6].

Indicator	Characteristic
Availability	Fintech market share across 48 fintech unicorns deserves over $187 billion as of the very first half of 2019, or slightly over 1% of the global financial industry. Fintech has reached an investment of $55.3 billion in 2019. China's share of the rate is $25.5 billion, of which more than half ($14 billion) is from Ant Financial of Alibaba Group, known for its Alipay mobile payment service. Return on investment in Fintech projects averages 20%.
Opportunities	Blockchain can reduce regtech costs by $4.6 billion annually. Increasing public access to variety of financial services without the involvement of traditional financial institutions, especially in developing countries. The availability of credit, investment and insurance through fintech programs will meet consumer and micro-enterprise needs. 82% of traditional financial institutions are going to partner with fintech startups in the next 3-5 years
Potential	Fintech has a CAGR of 25-30% over the forecast period 2019-2025. Blockchain and regtech (regulatory technology) are the fastest growing segments of the fintech industry. P2P or digital lending, another segment of fintech, has a value of $43.16 billion in 2018 and one is expected to grow to $567.3 billion.
Threats	Banks can lose $4.5 trillion in the payments and funds transfer market. Closure of traditional financial institutions branches due to fintech offensive with corresponding job cuts. The chaotic increase in the number of services provided by fintech companies, the increase in competition within the fintech, which will worsen customer service as a whole.

The basis of modern fintech is the technology of making payments and transferring money. It is direction most sought after by consumers of financial services. Consumers have the highest number of complaints to traditional banks about the duration transfer of funds and the high commission.

Banks receive a large enough commission for these operations. The commission share in total income of Ukrainian banks is illustrated in Table 2.

There are restrictions on cash payments, and businesses and entrepreneurs are required to open a bank account for non-cash payments when registering in most part of the world. This has advantages for the existing banks over other economic entities. For instance, banks have a source of funding for commission, even during the financial and economic crisis, when the business activity's level dropped. Some banks are raising the commission at this time.

The high commission rates are explained by the usual desire to make a profit and the need to finance the banking infrastructure where the highest costs are associated with maintaining offices.

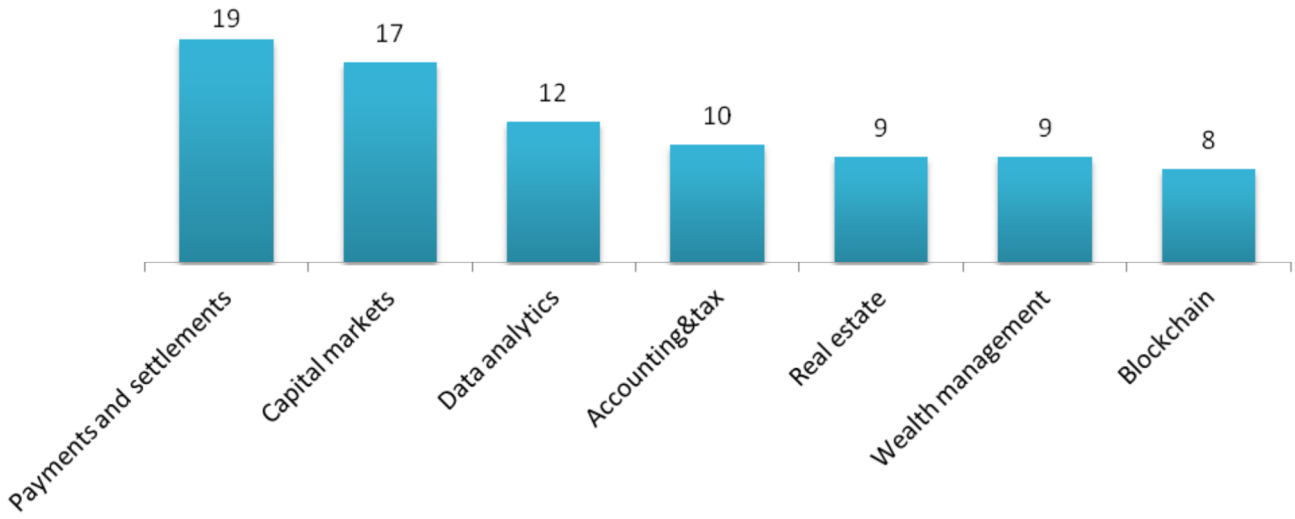

Fig. 2. Top US fintech startup segments, by number of US bank investors [7].

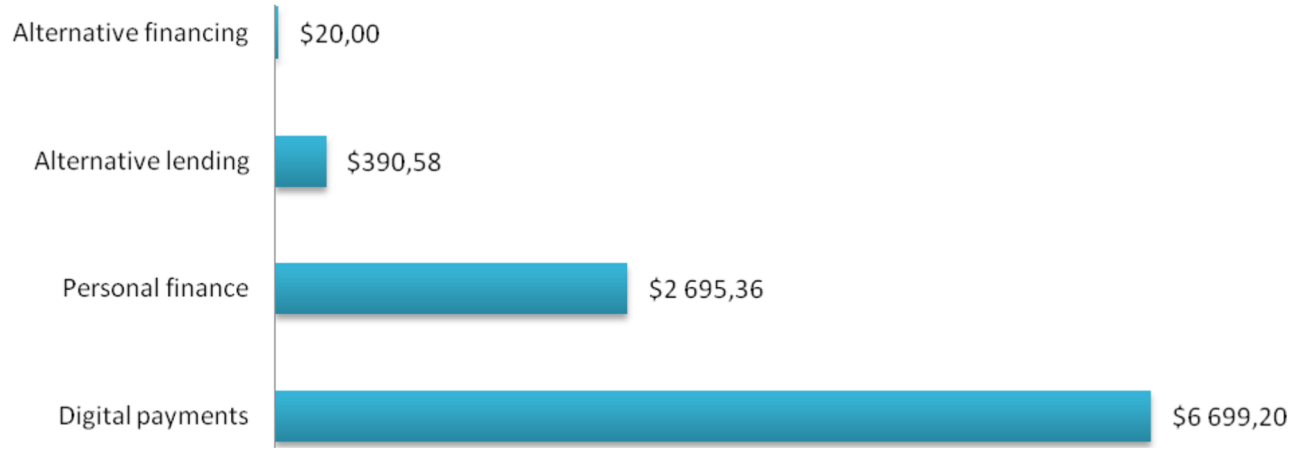

Fig. 3. Top fintech segments by transaction value, in millions [7].

Table 2. Share of commission in the income of Ukrainian banks (January-November 2019), mln. UAH [9].

Rate	January-February 2019	January-March 2019	January-April 2019	January-May 2019	January-June 2019	January-July 2019	January-August 2019	January-September 2019	January-October 2019	January-November 2019
Income	39279	58012	77064	98854	121064	141401	164990	183996	201037	222073
Commission	9164	13968	18939	24338	29114	34754	40047	45440	50687	56073
Share of commission	23,3	24,1	24,6	24,6	24,0	24,6	24,3	24,7	25,2	25,3

Fintech companies have the opportunity to provide low-fee services because they do not have offices or spend money to maintain them. In addition, fintech companies can generate value through related services (advertising, consulting, cross-selling and accompanying sale). An illustrative example is the transaction using the distributed registry technology, which took place on December 6, 2014: the $81 million transaction was carried out immediately, in real time, for 4 cents [10].

In addition to the high commissions, the speed of transactions by traditional banking institutions deserves comprehensive criticism. It takes several days to transfer money to another country through SWIFT. Fintech companies often offer real-time transactions.

Thus, the field of payments and transfers of funds is a segment in which banks can lose to fintech companies, if they do not make any changes in their technologies.

M-PESA payment and transfer operator and Kenyan banks is the prime example. M-PESA is Africa's most successful mobile money service. It provides access to financial services to the millions of people who have a mobile phone, but do not have or have only limited access to a bank account. M-PESA provides people with a safe, secure and affordable way to send and receive money, top-up airtime, make bill payments, receive salaries, get a short-term loan and much more. Established on 6th March 2007 by Vodafone's Kenyan associate, Safaricom, M-PESA is Africa's leading mobile money service, with over 37 million active customers and almost 400,000 active agents

operating across 7 countries: the Democratic Republic of Congo, Egypt, Ghana, Kenya, Lesotho, Mozambique and Tanzania.

In the Fiscal Year 2019, 37 million active customers carried out over 11 billion transactions, averaging over 500 transactions every second in December 2018 [11].

M-PESA has gained considerable success immediately since its introduction. This was manifested in the rapid growth in the number of system subscribers. Soon enough, Kenyan banks realized that a new competitor was actually jeopardizing their payments and money transfer business. A mega conflict arose at the end of 2008. Banks set themselves the task of completely eliminating a competitor. But M-PESA had in fact been belonged to the state, which resolved the conflict in its favor.

In the face of a multipronged onslaught from Kenyan Banks, M-PESA is not done proving its worth as the leader and innovator in offering mobile phone-based financial services.

M-PESA had at launch secured the full backing of the banking industry regulator in Kenya, the CBK, with its promise to deepen access to financial services in Kenya. While the delivery of M-PESA initially relied on Safaricom's dealer network, and later independent M-PESA agent networks, banks in Kenya moved to embrace M-PESA, if only to gain access to Safaricom's ever-widening subscriber base, a good percentage of whom were using M-PESA to conveniently perform financial transactions.

It is now clearly emerging as no secret that while banks started to embrace M-PESA in 2009, integrating their services with the former, they had their product development teams working overtime to develop mobile banking and mobile money platforms of their own, several of which have been launched this year.

Prior to this, when Kenyan banks woke up to the realization that M-PESA's strength was in its ubiquitous agent network offering cash-in/cash-out services, they moved to develop partnerships with retail outlets in an agency banking model approved and passed by the CBK in 2010. In what can be seen as good business foresight, M-PESA had made its agency contract with M-PESA agents exclusive, meaning M-PESA agents were off limits to banks as agency banking outlets.

Equity Bank, as the largest bank in Kenya by customer base, came close to unlocking this exclusivity when it partnered with Safaricom to launch M-KESHO in 2010. M-KESHO is a service that allows deposits to, and withdrawals from, one's Equity bank account through selected M-PESA agents and through the M-PESA menu. M-KESHO reached over 600,000 customers in a record 3 months, but unresolved teething pains prevented M-KESHO from replicating M-PESA's viral success.

While agency banking was instrumental in spreading banking services, the convenience of having one's money secured in a mobile phone 24 hours a day still gave M-PESA, and other mobile money transfer services that followed a big advantage [12].

Credit operations are brought the highest income to banks, and deposits of individuals and ones of legal entities are a resource base for them. Banks are practically protected from competition in this direction. You must have a banking license to conduct credit and deposit transactions. License requirements are set out in the Regulation on Bank Licensing [13].

The requirements are very stringent both in terms of material and financial resources and staffing. There are no fintech companies in Ukraine that which could be licensed and would be able to conduct deposits and lending operations.

But there are other situations in the world. For example, China is leading the digital banking world because of the launch of full-fledged digital banks called WeBank and MyBank. Tencent's social network and Alibaba's online store became founding members of the banks. The banking license was issued in 2015, but was restricted: banks were not allowed to open offices and receive deposits. Thus, the authorities tried to keep these banks from directly competing with state-owned banks. These banks, at the beginning of their development, have focused their efforts on Chinese residents who did not have bank accounts and access to financial services [10].

There is a two-tier banking system worldwide, where the first tier is represented by the central bank and the second level by commercial ones (state and non-state ownership). For a long time, such system is the basis for the monetary system functioning in a market economy. Thanks to this system, governments can impact on money supply, credit activity and business one, and inflation. Accordingly, governments will protect this system from uncontrolled changes that may disrupt equilibrium. On the part of the state, there are fears that an ever-increasing number of poorly controlled fintech companies will cause chaos in the financial market. After all, they generate a large number of projects in the area of money, credit, deposits, investment operations and insurance. Therefore, banking license availability protects banks from competition from fintech companies in the most important segment of deposit and credit segment.

Banks may be interested in working with microfinance fintech companies as well. This area is of little interest to banks because of the difficulty in administering (by current banking technologies) and low profits. Fintech companies can make money in this area because they have new technology management capabilities that are mobile and personalized, and they do not have to spend on maintaining the banking infrastructure.

P2P lending plays a considerable role among the alternative to traditional banking technology. P2P stands for peer-to-peer or person-to-person lending, which means peer lending. In other words, it is lending to an individual by an individual [14].

The pioneers in P2P lending world were the United Kingdom and the United States. The first such site was created in 2005 and provided exclusively for consumer loans. Today, the range of available loans is not limited to anything, large companies are coming to online sites, and the need for corporate financing is increasing.

Experts note the popularity of this area. So, in 2012, a few years after the big financial crisis, the global volume of P2P lending was about $1.2 billion. In 2017, analysts called the figure $64 billion. And according to Morgan Stanley,

by 2020 the market will reach $300 billion. Since 2016, this financial sector has begun to soaring - by 53% year over year. This can be explained by the increase in requests for P2P lending from SMEs. Now, analysts are talking about 120% of the annual average increase. And there is no reason to stop now [15].

Based on the content of P2P lending, it should be noted that it will be much cheaper, because one of the components of the banking interest is the cost of maintaining the banking infrastructure. P2P lending is otherwise called peer-to-peer lending. As the name implies, borrowers and investors are often individuals. At the same time, there is no intermediary (bank) between them, which allows to set adequate interest rates, determine the optimal deposit sum, establish favorable loan servicing conditions and avoid large commissions. Small percentages and commissions are also achieved by the fact that there is practically no administrative staff in the classic P2P lending scheme or crowdfunding and the office is replaced by a digital platform (Figure 4).

Under this scheme, a fintech company that has created and presented a digital platform is in charge of managing the whole process and thus becomes a competitor to traditional banks or investment companies. But there are several problems. The first problem is trust in the platform and the fintech company to ensure the process of saving money. The second problem is the lack of funds raised through the platform to achieve the goal of the process. In either case, traditional banks or an investment firm can become partners and solve both problems. A bank can act as a guarantor of saving money or provide the missing amount on favorable terms.

An illustrative example is the Brazilian Banco Original, which provides crowdfunding for the purchase of new cars in order to provide its customers with discounts and favorable credit [10].

The bank has the resources to buy a large batch of cars, which will provide it with a discount from the manufacturer, and a crowdfunding platform provides customers. Buyers also become bank customers (Figure 5).

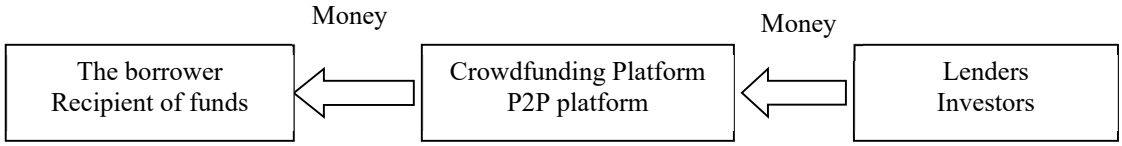

Fig. 4. Traditional P2P lending and crowdfunding scheme (mediation is not required).

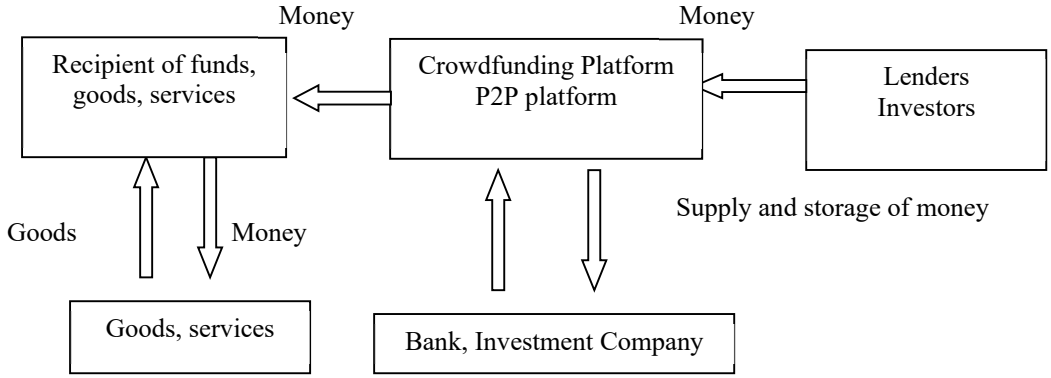

Fig. 5. P2P lending and crowdfunding scheme where the bank or investment Company is a partner.

Fintech companies have limited opportunities to enter the crowdfunding market in Ukraine. The limitation is due to two factors. The first factor is psychological. Public confidence in the banking system is still low and the more recent fintech companies (an absolute majority of the population know so little about both fintech companies as a phenomenon and the services offered by fintech).

Modern Ukrainian history is a history of crises, including financial crises. It is worth mentioning that in the collapse of the USSR, the overwhelming majority of Ukrainians lost their savings completely, which were retained in the accounts of the State Bank and the State Insurance Company. Already in recent Ukrainian history, people had been losing money in the financial pyramids of 1993-1994, as a result of the crisis in the financial system in 1998, due to the factors of the impact of the global crisis of 2008 and after the crisis caused by the events of 2014. The number of operating banks decreased from 180 to 75 in 2014-2020. It is extremely difficult to build trust in existing and new financial institutions in such circumstances. The second factor is resource. The population has little purchasing capacity and it is difficult to form a crowdfunding platform to buy expensive goods or starting a business. A possible solution is to form a crowdfunding platform as a joint product of a well-known bank and a fintech company. The bank provides the necessary financial resources and its brand (if the bank is reliable) to increase the credibility of the transaction.

Increasing trust in financial services provided by non-banking financial institutions, including fintech companies, is a matter for the companies themselves. They need to made an information and promotional campaign primarily through social networks. New technologies, such as Big

Data, provide the ability to personalize the needs of most members of social networks.

In October 2018, the number of regular Internet users in Ukraine was 63% of the population (20.8 million people). According to a Factum Group Ukraine poll, 70% of regular users use a smartphone to access the Internet. According to a survey by the Research & Branding Group, in early 2019, more than half of Ukrainians (55%) had already a device like a smartphone, while 45% had not yet purchased one. In March 2019, Facebook was the most popular social network in Ukraine, used by 50% of respondents. Research data from Research & Branding Group show this. According to sociologists, since May 2018 in Ukraine the number of social networks users such as Facebook (up to 50%), YouTube (30%), Instagram (27%) has significantly increased and the number of social network users such as Classmates (6%) and VK (10%) has slumped [16].

20-25 million Internet and social network users are significant opportunities for traditional financial institutions such as banks, insurance companies and fintech companies. In fact, these are real and potential consumers of financial services.

It is now possible to distinguish two leaders in digital adoption in banking. The first is the state-owned CB "Privatbank" whose payment system "Privat 24" is very popular among population: at the beginning of 2020, 10 million Ukrainians used this app [17].

The Bank has more than 20 thousand terminals and ATMs and 6440 thousand depositors. Among additional banking services that are in demand among consumers are the purchase of tickets for transport; calling a doctor; repayment of a part of the spent money on bonus programs, purchase of domestic government bond. Recently the bank has launched an online purchase service. Once purchased, product will be stored securely at the bank.

CB "Privatbank" implemented a very interesting (and today unique in the bank insurance) project until nationalization, which took place in 2016. The Bank was founded the insurance company PJSC "Ingosstrakh". Initially, it employed 38 people, the company had no offices. All insurance services were provided exclusively in electronic format, and CB "Privatbank" was the only agent of this company. The project was a huge success. For two years, the company entered the TOP 5 Ukraine insurers by volume of insurance premiums received (first place in 2016 by premiums in accident insurance). As a matter of fact, the project abolished the ban on banks to engage in insurance activities that has been operating in the EU and Ukraine. The project was curtailed after the bank nationalization.

On the example of CB "Privatbank" we can see a combination of financial and non-financial operations. It is this business model is likely to be trending in the coming years.

The second technological leader in banking is the TAS financial group. The Group combines assets in industry, agriculture, development, banking and insurance. In November 2017, some of the executives of CB "Privatbank" (the nationalized bank at that time), have founded the Fintech Band and have developed the Monobank app. One is positioned as a bank without offices. In fact, it is Universal Bank's retail product (it was founded in 1994, and since December 3, 2016 it is TAS group part), which originated in cooperation with the Fintech Band team. Credit cards for customers, deposits and other services are issue taking place within Monobank. The best mobile app makes managing customers' finances as convenient as possible. Monobank only works on mobile devices. The Fintech Band team employs more than 100 people, mostly from PrivatBank.

Monobank's investment amounted to $2 million, which the Fintech Band expects to return in one to two years. The Fintech Band is going to get their money back and make a profit as follows: to sell its platform and complex of accompanying services to other market players. The company has already made deal with two banks. Initial investment in the Monobank project draws attention by a small amount, even by Ukrainian standards ($ 2 million). It should be added that most users consider Monobank services to be a bank and not Universal Bank's structural unit [18].

The first attempt to launch the P2P lending platform in Ukraine was made by CB "Privatbank" together with MasterCard in 2016. The new non-standard service launch can be regarded as a publicity stunt, due to the situation with Privatbank was very tense and difficult at that time.

Its purpose was to show that the bank is fine. After the nationalization of the bank, the program was curtailed.

FinHub has become the first platform of direct P2P lending without intermediaries in Ukraine. The company was able to create a high-end service that is a real alternative to traditional lending, based on a study of the world's best experiences of successes and mistakes. Secure payment processing using the latest technologies is carried out jointly with partners TASLink and JSC "TASCOMBANK".

FinHub offers its borrowers:

- it is possible to draw long-term (up to 15 thousand UAH up to 1 year) or short-term (up to 5 thousand UAH up to 30 days) credit;
- the cost of credit is much lower compared to online credit services and banks;
- there is no need to leave the house - the application process, scoring and accrual takes place online;
- only the passport and ID code are required for registration;
- there are no hidden payments, commissions, etc.;
- the loan repayment is also held online through the personal cabinet.

Investors benefit from work with FinHub because:

- it is a real modern and easy way to increase your income (up to 300% per annum);
- a large number of applications diversify risks;
- the sum of investments starts from 500 UAH;
- unscrupulous borrowers are eliminated at FinHub's automatic scoring stage;
- credit applications have all the key data (socio-demographic parameters, income levels, etc.) available to build a carefully thought out investment strategy [15].

It immediately attracts the attention that investors are offered earnings up to 300% per annum. The question

arose: How much should the borrower pay and whether such a loan is needed?

In Ukraine, P2P schemes and crowdfunding ones cannot gain rapid distribution. The options described are rather image samples of well-known market players in the traditional banking sector. Transformations caused by digital technologies can also occur within the financial institution itself. The Polish BRE Bank story, which was founded the mBank unit in 2000 to provide on-line services, is striking (it looks like the Ukrainian Monobank name is not fully original). Thanks to mBank launch, this bank has become Poland's largest online bank and the third largest retail bank. Due to its success, mBank in 2007 has expanded its operations to the neighbors markets – the Czech Republic and Slovakia. Having analyzed the success story of BRE Bank in 2013, it decided to rebrand the entire bank under the name mBank based on four principles: real-time marketing; personal financial management; mobile banking; social media [19].

Consequently, there are a lot of options for financial institutions transformations related to digital technologies. There can be no single templates. But not one financial institution is likely to can ignore the new realities.

Talking about finance and technology, one should not overlook the issue of cyber risk. Cyber risks are the risks that arise from the use and transmission of electronic data, including technological tools such as the Internet and telecommunications networks [20].

Cyber risks are consistently in the top 10 risks to humanity. The use of digital technologies in finance not only provides new opportunities, but also activates cyber threats in the form of unauthorized access to financial services of consumers' personal data. Not only personal data, but also real money of clients is threatened with theft.

Cyber-risk protection requires significant investment in security systems. Often, this is beyond the power of small fintech companies and new startups. Traditional financial institutions have a systematic approach and resources the struggle against cybercrime and this is a significant competitive advantage.

Conclusions

The financial ecosystem is changing rapidly under the influence of digital technologies. A new financial institutions layer, a fintech company, has emerged and is actively developing. New fintech companies compete with traditional banks and payment systems in areas such as payments and money transfer. But fintech companies are not competitors of banks in the traditional sense, because their share in the global financial market does not exceed 1%, despite its rapid growth in recent years.

The governments of the countries are interested in maintaining the traditional structure of the financial market, the two-tier banking system, as it protects the monetary system from chaos. Business and household confidence in banks is much higher than in fintech companies, despite the crisis events in the 2008-2009 (and in 2014-2016 in Ukraine). Banks have resources to world protect customers' information and money from all kinds of cyber risks.

In 2019, fintech investment has decreased. This can be associated with the market saturation digital financial services, many of which are complex and incomprehensible to consumers. The growth of the fintech sector can be expected in the insurance and private investment sectors, which are not as tightly regulated as the banking sector.

In general, traditional financial institutions and new fintech companies are doomed not to compete but to cooperate. Traditional financial institutions need new technologies, and financial companies need investment.

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Securitization as an innovative refinancing mechanism and an effective asset management tool in a sustainable development environment

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Abstract. Today's realities dictate to Ukrainian companies a management philosophy that requires them not only to maintain their position in the market, but also to increase the efficiency of their operations and development in the context of favorable and unfavorable changes in the market environment, which necessitates significant amounts of financial resources. In the face of global competition and the increased turbulence of the external environment, securitization is one of the alternative tools to attract additional financing as well as to minimize risks by which financial markets can support sustainable finance in the transition to a green economy. The article deals with the essence of securitization as one of the major financial innovations of our time. It is established that this financial mechanism allows to diversify sources of financing, to effectively manage the structure of the balance sheet of the enterprise, as well as to significantly increase the level of liquidity of its assets. It also describes the main types of securitization and their impact on the structure of balance sheet indicators. The practical relevance of the study is that the authors' highlighted areas of change in financial performance make it possible to make an smart decision on the use of a particular securitization mechanism, considering the purpose of its implementation and the capabilities of its initiators, including in the transition to a green economy. It is suggested for the successful implementation of the concept of a "green" economy aimed at achieving sustainable development goals in Ukraine, using such financial instrument as sustainable securitization through the use of the collateralized loan obligation mechanism.

1 Introduction

Uncertainty of business environment, constant competition, inflation growth rate, and deficit of available financial and investment resources under the conditions of the lack of own money stimulate economic entities (it concerns both financial sector and real sector) to search for new tools to rise extra financing. In this context, securitization as an innovative mechanism of the structured financing on favourable terms making it possible to attract finance while issuing and offering of asset-backed securities becomes extremely important.

In the context of the developed countries, securitization is generally recognized as the tool of advantageous funds raising; moreover, it is an integral part of a financial market. Securitization mechanism originated in the USA early the 1970th when, on the one hand, banks needed cushioning of risks, and on the other hand, population demonstrated increased demand for mortgage credits. Thus, the mechanism became a financial banking revolution.

First, it was implemented in the form of mortgage relations between banks and other business entities. However, from the mid 1980th, securitization contacts started to involve gradually different types of assets: autoloans; consumer credits; credit card payments; export deliveries; trade financing; factoring transactions; insurance payments; leasing payments; utility payments; municipal loans of states secured by budget receipts etc. In the second half of the 1980th, issue of asset-backed securities started in the majority of the developed countries including the United Kingdom, Germany, Italy, Spain, the Netherlands, France, Australia etc. However, Eastern Europe, and Central Europe "got to know" the mechanism in 20th century only. First of all, a degree of securitization relations in one or another country depends upon the legal system of the nation, development of its financial markets, currency limitations, tax laws, accounting rules, the current system of its governmental regulation, and transparency of economy.

In the context of the countries where securitization experiences its dynamic progress during the last decades, providing its participants with efficient tool of diversification of sourcing as well as risks of investment in different assets, new types of financial tools originated and access of new participants the market was afforded which favoured expansion of the world capital market and its extension while animating progress of the global financial industry.

In recent years, there have been a major structural

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transformation of the global securitization market, characterized by significant development of its such type as sustainable securitization, aimed at achieving sustainable development goals. This is due to what C. McGarry, D. Dey, and M. Hauman have noted, that the sustainable finance market has experienced exponential growth in certain product areas in the last 5 years. Annual green bond issuance, for example, passed the US $ 100bn mark last year and environmental resilience is playing an increasingly important role in investment decisions worldwide. However, US $ 90tn more in sustainable investment is needed to develop global sustainable infrastructure alone in the next 15 years [1]. Therefore, in order to enable institutional investors to invest in sustainable assets, the functioning of which is aimed at ensuring sustainable development (renewable energy, environmental innovations, circular economy projects, "green" buildings, sustainable agriculture, etc.), active implementation of sustainable securitization tools is necessary.

2 Assessment of securitization market

The total volume of the global securitization market at the end of 2013 amounted to more than 600 billion US dollars, and in 2018 reached almost 850 billion US dollars. Moreover, such issues in the world are half provided with a mortgage, one-third are loans for infrastructure projects and the real sector, and other issues are provided with distressed and other assets [2].

Generally, securitization development is not uniform both in terms of regions and in terms of the world countries (Fig. 1).

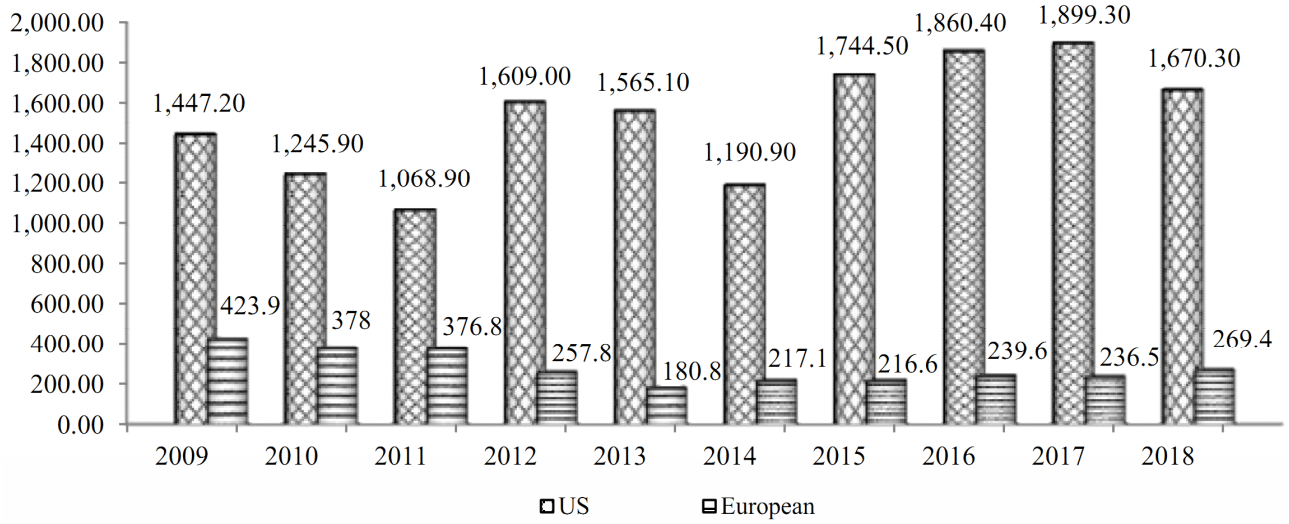


Fig. 1. European and US Securitization Issuance, € Billions (based on the reports on the securitization of ASIFMA [3], AFME [4] and SIFMA [5]).

The securitization market in the US represents 60% of the global market today. The crisis impacted heavily the volumes of US securitization which felt from over EUR 2,0 trillion in 2007 to EUR 915,8 billion in 2008 (inclusive of ABS, CDOs, Agency MBS and Non-Agency CMBS/RMBS) and have since recovered fully to EUR 1,9 trillion for all of 2017. All the asset classes (but private label MBS – which is nevertheless off its lows) showed an impressive rebound [6].

The securitization market in Europe was rather undeveloped till the late 1990th. Since then, there has been a significant increase in securitization activity. Many of the securitization products widely used by the financial industry across the world have been developed in the UK. The UK securitization is the largest market in Europe. The financial crisis in Europe made securitization plunge from EUR 819 billion in 2008 to EUR 423 billion in 2009 and steadily decreased to EUR 180 billion in 2013, before finally recovering at EUR 237 billion in 2017. It is interesting to highlight that European securitizations have held up very well through and since the crisis in both credit and pricing terms. European policymakers are making every effort to revive the market, since the rationale for securitization and the benefits it provides remain strong [6].

Europe saw a general spread compression which pushed investors to look for yield and hence supported deals with better pricing such as peripheral paper, CLOs, CMBS & non-prime RMBS In Europe, there are mainly three types of investors interested in securitization: a) institutions without deep multiple funding sources (e.g. challenger/smaller banks, non-bank FI's and PE houses off the back of acquisitions) or that have a strategic reason to securitise (i.e. showing liquidity for an IPO or deleveraging), b) peripheral jurisdictions, c) arbitrage players (e.g. CLO managers or bank underwritten CMBS), and d) the auto sector where spreads are very tight [7].

Europe's "Capital Markets Union" (CMU) is rapidly gaining traction. Announced in November 2014, the new European Commission (EC) under Jean-Claude Juncker quickly capitalized on the more buoyant post-crisis mood among the member states of the European Union (EU). In that context it kick-started a series of "public" consultations on what it deemed to be the key priorities of the set of proposals included in the original Green Paper [7].

In response to the increasing regulatory and policy

focus on Sustainable Finance (including the environmental aspects) in September 2019 AFME has published a position paper on Green Securitization in which we highlighted the key voluntary principles which policymakers and market participants should support to help propose green securitization. Among those principles, defining green securitization simply and clearly, as well as regulatory support and proportionate (non-duplicative) disclosures have been indicated as one of the most important factors [8].

In Asia, the regulatory and market frameworks governing securitization are relatively nascent. Domestic securitization markets are more active relative to their cross-border counterparts. Crossborder issuance, which is only a fraction of US and European issuance, dropped sharply post 2008 as the market for CDOs (which accounted for the bulk of Asian issuance pre-2008) virtually shut down. It is worth noting that, as long as Asian companies will be able to obtain cheap funding in their local capital markets, they will not look to cross-border securitization deals [6].

Changes in the market of securitized assets are determined by various factors, including the economic situation in regions, countries and individual sectors of the economy; conjuncture in the financial markets; fiscal policy; regulatory and supervisory requirements; the methodology of rating agencies regarding the valuation of assets under consideration. An analysis of the data presented allows us to talk about stabilization trends in the global markets for securitized products. As foreign experience has shown, the impact of securitization on financial systems in different countries may be different due to the dissimilar structure of these systems or differences in the way monetary policy is implemented.

All in all, the last decades expanded significantly the circle of assets used during securitization. In addition to mortgages, other loan types (i.e. consumer credits, auto loans, business credits, credit card payments etc.) started to be applied. What is more, lease assets; money claims under the license agreements and franchise agreements; future insurance premia; proceeds of oil importers; and transfers for broadcasting are used as the assets. Furthermore, export earnings, oil and gas rights, payments for transportation services (i.e. air and railway tickets), telephone bills; utility payments; lottery gains; and entertainment revenue are the assets involved in securitization (Table 1).

Currently, large power companies, broadcasting companies, gas companies, coal companies, and oil companies (i.e. so-called capital intensive-companies which cannot go without loan money and for which introduction of such a scheme would cut assets critically) are the potential imitators of securitization. Mechanism of securitization is a real thing to finance infrastructural projects and to develop financial leasing, insurance market, modern wholesale and retail trade networks, export-import relations etc.

Copyright application is a case of point of flexibility of investors as well as other financial market participants as for the basis assets in the securitization process. Actually, issue of Bowie bonds in 1997 to the amount of 55 million USD based on the royalty paid for British artist for the use of more than three hundred music composition has become the first example [9].

Table 1. Objects of securitization depending upon its initiator.

Securitization initiator	The assets to be securitized
Banks	Mortgages; commercial credits; consumer finance; autoloans; student loans; credit card debts; lease payments; and factoring payments
Lease companies	Payments by lease agreements
Factoring companies	Factoring payments
Insurance companies	Insurance premia
Corporations	Export earnings (future accrual from economic activities (inclusive of trade); money claims against license agreements; and against franchising agreements
Broadcasting companies	Future proceeds from broadcasting; and rents from the equipment used
Mobile communication companies	Future proceeds from subscribers
Oil and gas companies	Future proceeds from oil importers; and rights for oil extraction and gas recovery
Public utilities	Community charges; and future proceeds from electricity, water, and heating
Transportation companies	Future proceeds from air and railway tickets
Entertainment companies	Future earnings in the sphere of film and sports industries; and proceeds from future sales of the recorded music
Bodies of public authorities and local authorities	Tax revenue; and another regular budget revenue

However, one of the most urgent areas of investment in the face of exacerbated social problems, scarcity of resources, environmental and climate risks at the current stage of society development is sustainable assets used in the securitization process. This is due to the fact that in the context of the active introduction of the concept of sustainable development in the world into companies' activities, thanks to the support in 2015 of 17 UN Sustainable Development Goals in all 193 countries, the market of investments in sustainable assets is growing exponentially and this trend will continue in the next decade. For example, according to OECD representatives' calculations, there will be a steady increase in investment needs for sustainable assets (Table 2).

Table 2. Annual investments needs for renewable energy, energy efficiency in buildings and low-emission vehicles in a 2DS compared to global energy sector needs, 2015-2035 [10].

Indicators	2015 – 2020	2021 – 2025	2026 – 2030	2031 – 2035
Renewable energy, energy efficiency and low-emission vehicles investment needs in the four markets (China, EU, Japan and United States), billion	573	1315	1264	2262
All global investment needs for energy supply and energy efficiency, billion	839	2230	2404	4340
Share, %	68	59	53	52

3 Eclecticism of fundamental notions of assets securitization

In his paper, titled as "The Alchemy of Asset Securitization", Steven L. Schwarcz [11] describes securitization as alchemy of the current financial market which can transform lead to gold, i.e. a right of money claim to securities. Moreover, he focuses attention on the fact that securitization is as profitable as it can form capital right at the expense of securities market where capital value is relatively lower.

"Life after life" is the definition by A. O. Soldatova characterizing a destiny of asset rebirth at a capital market after their securitization [12].

The term "Securitization" originated from "Bank of America issue" agreement. It was first proposed in 1977 by Lewis S. Ranieri, who headed a Mortgage-Trading Desk of Salomon Brothers, to Ann Monroe, are porter of Wall Street Journal, to help her describe underwriting of the issue of securities by Bank of America backed by a pledge of receivables in terms of mortgages. The operation relies on a pass-through structure when a special purpose vehicle (SPV) distributed all the funds, "generated" by credit pool at the time of payments for such financial credit documents, among security holders [13].

Despite the fact that the concept originated at the turn of the 1970s, scholars do not have any identity of views concerning the idea of asset securitization. Like that, such Western researchers as R. Berry and J. France [14] supposed there were almost 279 definitions of securitization in the early 1990th only in London.

In this connection, Hans Peter Bär, famous Swiss securitization scholar, believes it is required to bear in mind a number of factors while considering all the available definitions. First, attention should be focused on the fact that some of them emphasize either certain elements (for instance, asset pool sale; use of the pool to back the securities) or a fact of risk separation and transfer. Second, there are numerous efforts to make a definition which would involve all possible variants inclusive of asset-backed transactions, project financing or even crediting followed by a backing of assignment of receivables. Moreover, rather often the terms "asset securitization" is applied improperly. Most probably, the annoying misunderstanding can be explained by the fact that asset securitization is not a well-defined operation; depending upon certain jurisdiction and customer needs it is based upon individual approaches taking into consideration a specific situation, i.e. it is a tailor made financial solution [15].

It should be noted that in his monograph titled as "Asset securitization: securitization of assets – innovative technique of bank financing", which became the classic securitization manual for Swiss, German, and Austrian bankers, H. P. Bär differentiates the two concepts: "securitization" (i.e. securitization in a general sense), and "asset securitization" (i.e. securitization in a narrow sense):

- in a general sense, securitization is understood as a shift of international financing from a credit market to a money market, and to capital markets; replacement of credit financing by schemes based upon the issue of securities; and disintermediation;
- in a narrow sense, asset securitization is: innovative financing technique; specific form in terms of general tendency for securitization. Its basic idea is to write down financial assets from an enterprise balance and to refinance them by means of security issue at the international market and at a capital market. Mortgage-Backed Securities (MBS) and Asset-Backed Securities (ABS) are the key tools [15].

Etymologically, the word "securitization" comes from the English "securities". Economic meaning of securitization relations is understood as a movement of money (inclusive of its attraction) with the help of securities rather than traditional bank credits. Having formed asset pools, market participants as the subjects of securitization relations, issue securities for their backing and convert them at a capital market. Hence, while raising the finances, the market participant can direct them to implement new relations inclusive of extra profit taking in the form of a difference between asset interest and security interest which is favourable for turnover of funds [16].

To support the abovementioned, J. Tavakoli [17] defines securitization as a market economy conception which forecasts a subset of tools of the structured financing. In substance, it is the creation of securities backed by asset pool (portfolio) and their issue; as a rule, the asset debtors vary. Actually, any combination of financial assets or cash flows may be converted into market securities to sell them to investors, i.e. securitized.

The analysis of recent studies and publications concerning the idea of asset securitization, helped identify the basic concepts of the process mentioned in the definitions of scholars:

- financing (refinancing) method (type);
- issue of securities backed by a pool of homogenous assets;
- process (method) to transform (convert, repack) low liquid assets in liquid ones (i.e. securities);
- process (mechanism) involving a number of successive stages (steps); generally, obligatory stages are: formation of the diversified pool of homogenous financial assets; its writing-down from the securitization initiator balance by means of their transfer to a specially established company; issue of securities, backed by the assets, by the company, and their placing among the investor community;
- method of risk hedging;
- process to increase the role of the securities to compare with bank crediting.

We believe that on the whole, securitization is one of the financing types relying upon the use of tools of security market. Thus, asset securitization is a narrower conception; it characterizes a process of issuing and servicing of securities backed by a flow of payments generated with the help of the separated pool of homogenous assets. In this context, the asset pool is understood as a collection of rights of a money claim.

4 Securitization mechanism

In general, asset securitization mechanism forecasts that its initiator, being an originating company (i.e. banks or other financial institutions; nonfinancial corporations; governmental authorities; public utilities etc.) generates assets in the process of its operational activities (for instance, while disbursing loans; delivering goods; providing services inclusive of demising etc.). As a result, the company becomes the owner of assets, i.e. claims for the third parties (debtors). Further, the claims form asset pool. To back them up, securities are issued with their following monetization at a stock market. Payment flow and credit backing characteristics identify quality of the issued securities while specifying both monetization and structurization of the asset securitization.

While raising money in such a way, the economic agent is permitted to use it for the implementation of new relations inclusive of making extra profits in the form of difference between the asset interests and security interests which favours the money negotiability.

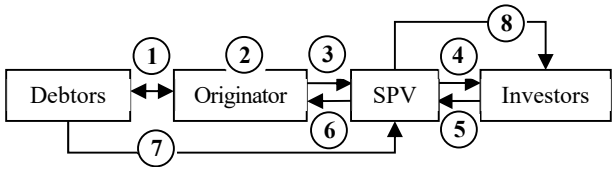
It is obvious that the asset securitization process involves a number of economic mechanisms covering rather broad spectrum of participants and specific agreements developing certain complex which in turn can vary significantly and be supplemented depending upon the object and possibilities of securitization initiators. Hence, A. A. Kazakov considers that even shallow analysis of security issue prospectus in terms of the securitization has shown that the current agreements are participated by almost fifteen counterparties among whom more than a dozen of various contracts are effected [13]. Asset-backed debtors (i.e. direct debtors); initiator being the asset owner as well initiator of the securitization process itself; Special Purpose Vehicle issuing securities in terms of the classic securitization; investors discounting the news; hedge providers hedging both currency risks and interest risks; rating agencies evaluating reliability of the issued securities and expressing their independent opinion concerning credit quality; insurance companies acting as guarantors and running the risks connected with the securitization process; legal companies engaged in contractual process; accounting and auditing companies, and many other participants. Such a great number of professional participants make it possible to carry out unique operations since they fulfill their functions more effectively and less costly to compare with other people.

Relying upon the abovementioned and following the source materials interpreted by us [11, 12, 15, 18-24, 27], we have identified that following obligatory features are typical for asset securitization:

- The assets to be securitized should generate such money flow which can be measured and forecasted;
- The formed asset pool should be able to be separated (either mechanically or juristically) from other assets of the company;
- Debt securities, issued during securitization, should be backed by a pool of homogenous assets;
- Purposely established company of personally initiator of the securitization may be issuers of the debt securities;
- Initial assets, underlying the agreement, back up the assets within the securitization system, i.e. money flows through the securitized assets should be the source of interest payment as well as the principal on the issued securities;
- Risk management as for the separated asset pools is performed by means of their complete transfer to the investors or their partial transfer.

It is understood that asset securitization is rather complex and multiaspect mechanism; therefore, securitization agreements differ greatly. However, the current world practices identify its two basic models depending upon the securitized asset location, purposes of the initiator, and securitization procedure. They are: off-balance-sheet model and a balance-sheet one. Mainly, they differ in the fact whether the assets are liquidated or not.

Classic (i.e. traditional) off-balance-sheet securitization is based upon a “true sale” scheme characterized by transfer of asset pool to be securitized to a specially established mediator, i.e. Special Purpose Vehicle (SPV). In turn, such a financial mediator put up money for the purchase of the assets by means of issue of securities backed by future cash flows from the assets and provides their distribution among investors at the capital market. Following payments of debts and interest by owners of the issued securities are carried out at the expense of funds provided from debt recovery by borrowers where claims are transferred from initiator to SPV (Fig. 2).



1) origination of a monetary claim rights (origination of debtors); 2) formation of homogenous asset pool; 3) sale of asset pool to SPV (“true sale”); 4) issue of securities backed by the purchased asset pool; 5) payments for the purchased securities by investors; 6) cancellation of the purchased asset pool; 7) payments of interest and the principal by debtors according to the effected agreements; 8) security debt repayment to the investors

Fig. 2. Model of the off-balance-sheet (classical) asset securitization.

The initiator bankruptcy cannot stop credit portfolio servicing; if default of the portfolio share takes place then junior tranche assumes the first risks.

The basic investor risks, resulting from asset securitization, depend directly upon SPV activities. In this context, investors are not interested in the constant control over SPV operations. That is why, international practices have gradually developed specific requirements for SPV legal status providing adequate protection of rights and interests of investors, and management of their risks connected with the purchase of asset-backed securities. Among other things, following requirements favour minimization of SPV bankruptcy risks:

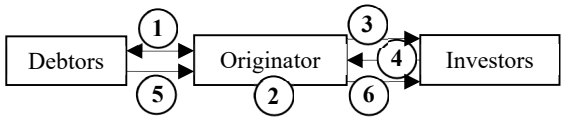
- SPV independence from the initiator (SPV is established separately, being free of the initiator economically and

legally to prevent its joining the consolidated group of a primary owner of asset pool and to avoid potential after-effects of insolvency);
- SPV bankruptcy protection (SPV development should involve impossibility of its voluntary bankruptcy and liquidation as well as merger with another enterprise or other reorganization forms);
- SPV limitations as for the carrying out of various activities, i.e. special franchise (primary objective of SPV is to purchase asset pool from the initiator, and issue of securities backed by the asset pool. Hence, organizational structure of SPV should be limited by strictly determined activity types and it cannot involve any other employees in addition to those needed directly to implement securitization agreements).

Thus, the traditional scheme prevails in the legal determination of the securitized assets of the initiator and, consequently, in the related risks which makes it possible (to compare with the agreement initiator ranking) to increase investment ranking of the backed security issue becoming dependent upon asset quality only. Therefore, in the process of decision making, the investor may focus exclusively on the asset quality (i.e. rights of monetary claims) as well as on the reliability of the structure of agreement under consideration. The rating margin forms a basis to benefit economically from securitization.

Nevertheless, the mechanism is not free from disadvantages. First of all, they are: high cost of the "true sale" (average pool of homogenous credits is 100 million USD); the necessity to disseminate confidential information concerning borrowers; grave legal obstacles; taxation problems etc.

That is why, taking into consideration the limitations, arising in the process of the classic scheme to securitize assets, its alternative model has been developed. Balance-sheet securitization is meant which anticipates that assets are still owned by a company initiating the securitization; consequently, the company issues individually securities backed by the assets (Fig. 3).



1) origination of debtors; 2) formation of homogenous asset pool; 3) issue and placement of debt securities, backed by homogenous asset pool and prospective income from them; 4) debt security payment; 5) debt service payment according to the agreements; 6) coupon payments to investors on the debt securities, and their cancellation when term of the debt repayment is over

Fig. 3. Model of the balance-sheet asset securitization.

Under such conditions, credit rating of issue of debt securities cannot be higher than credit rating of the issuer; in turn, the above prevents from cost cutting of the securitization initiator as for the debt servicing due to the high quality of the loan security. For instance, in the context of credit institutions, the method is expedient if asset pool is formed from low-risk credits, and their write-off may worsen qualitative characteristics of credit portfolio of the bank.

In such a case, exclusion of the securitized assets from bankruptcy of the initiator company takes place by means of asset pool separation from the total competitive amount and by means of legislative recognition of privilege of shareholders (i.e. investors) for the asset pool to compare with other creditors.

Typically, the world practices apply the balance-sheet model to hedge risks; if so, synthetic securitization is meant.

Basel Committee on Banking Supervision [25] interprets synthetic securitization from the viewpoint of a tool of credit risk management supposing that they are "the structured contracts where banks use credit derivatives to transfer credit risks of a certain asset pool to the third parties inclusive of insurance companies, other banks, and uncontrollable individuals". Schengzhe Wang [24] believes that the synthetic securitization purpose is the use of credit derivatives to synthesize economic effect of traditional securitization.

Cornerstone of synthetic securitization is a mechanism in terms of which the securitized assets is not sold from the legal point of view remaining on the balance of the initiator company; at the same time, the risks, connected with the assets, are transferred to a market. Namely, to compare with the classic securitization, the synthetic model does not involve true sale of the assets. Separation of credit risk from the securitized assets is performed synthetically on the basis of credit derivatives, i.e. agreements according to which one party, acting as a protection seller, transfers a credit risk of a special debt or portfolio debt to another party (i.e. protection buyer) for a fee. In turn, the latter makes payment to the protection buyer if a risk (credit) event happens. In other words, credit risk becomes characteristic goods for which a market is made; in this context, a price of a credit risk of each borrower is determined by a mechanism of supply and demand.

A protection seller should understand clearly what problems will be solved with the help of the synthetic securitization in terms of each specific case; the information is the basis to select adequate structure which in turn can be implemented either using SPV or without its establishment.

Generally, synthetic securitization is a so-called method of credit risk mitigation (CRM) to hedge and expand risks connected with the securitized assets when the risks transfer synthetically from one party to another one, i.e. without basic liability sell.

Hence, by its economic nature, balance-sheet securitization (inclusive of synthetic one) simulates after-effects of the traditional securitization; however, despite that fact, they differ principally (Table 3).

Anyway, both off-balance-sheet securitization and balance-sheet one are financing mechanisms. In this context, their key difference is a method of asset pool placement, i.e. corresponding assets are either written-off from the balance of the securitization initiator or not. As a matter of fact, the above influenced the name of the securitization types. Certain agreements of a balance securitization (in particular regarding synthetic one) turn out to be cheaper to compare with the traditional one (i.e. off-balance-sheet) since SPVs are not established and

special structure to back sales conditions is not required. Moreover, off-balance-sheet securitization has numerous legal restrictions; thus, it is more expensive than balance-sheet one. In addition, selection of one or another securitization type governs rating of securities since their issuers will differ as well as risk transfer degree. What is more, influence on the indicators of financial and material state of the company will also vary.

Table 3. Comparative analysis of the balance-sheet asset securitization and off-balance one (generalization of materials [15; 18; 27]).

Comparison criterion	Securitization type	
	Off-balance	**Balance**
Asset pool placement	Write-off from the initiator's balance	On the initiator's balance
Issuer of securities	SPV	Initiator, SPV
Payment source on the principal debt and interest	Cash flow generated from the asset pool wrote-off from a balance	Asset pool (i.e. cash flow of an issuer)
Liability of an initiator	Within coverage of the credit as well as of extra security	Own capital liability
Bankruptcy of an initiator	No effect on the repayments	Bondholders have the prior right to satisfy their claims
Credit rating of securities being issued	High rating depends upon credit quality of the securitized assets	Depends completely upon the initiator rating
Credit risk bearer	Investor, insurers, SPV	Issuer
Bearer of a prior repayment risk	Investor	Issuer

5 Securitization influence on the indicators of financial and material state

Since off-balance-sheet securitization scheme involves the fact that the transferred SPV assets are replaced by the money raised from the sale of securities backed by the same assets, thus no significant changes take place in the asset value of the originator company; only their structure varies (Fig. 4).

Hence, asset separation to mitigate risks is possible if following basic conditions are fulfilled: use of a "true sale" scheme; bankruptcy protection; minimum of own SPV capital; and no originator-SPV consolidation.

In the process of balance-sheet securitization, asset value of the originator company, being also the security issuer, changes in their structure take place through the increased liquid assets which resulted from the security conversion (Fig. 5).

In other words, company assets represent the originator function and company liabilities represent the functions of issuer of the securities.

The abovementioned helps conclude that off-balance-sheet securitization, and balance-sheet one influence distinctly the financial and material condition of the originator company; first of all, that concerns such indicators as total balance, composition of assets and liabilities and their structure, indicators of liquidity and financial stability; indicators of financial results and profitability, and indicators of business activity (Table 4).

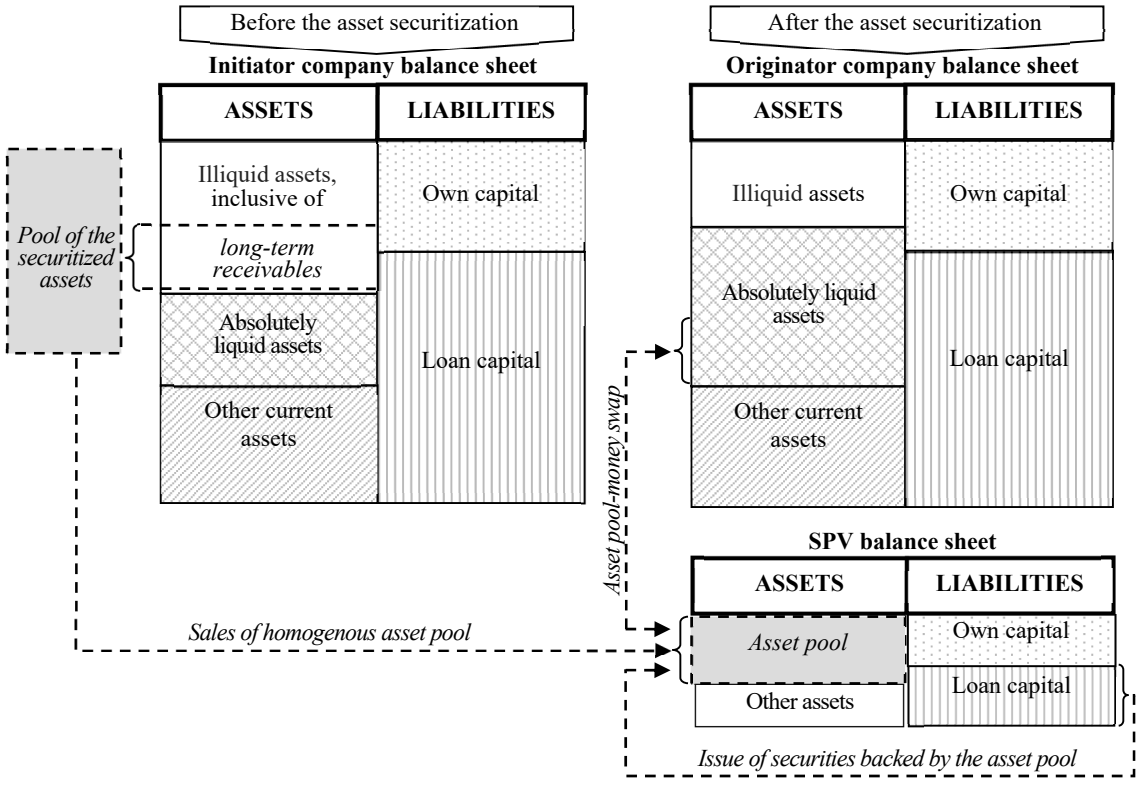


Fig. 4. Influence of the off-balance-sheet securitization on the balance-sheet indicators.

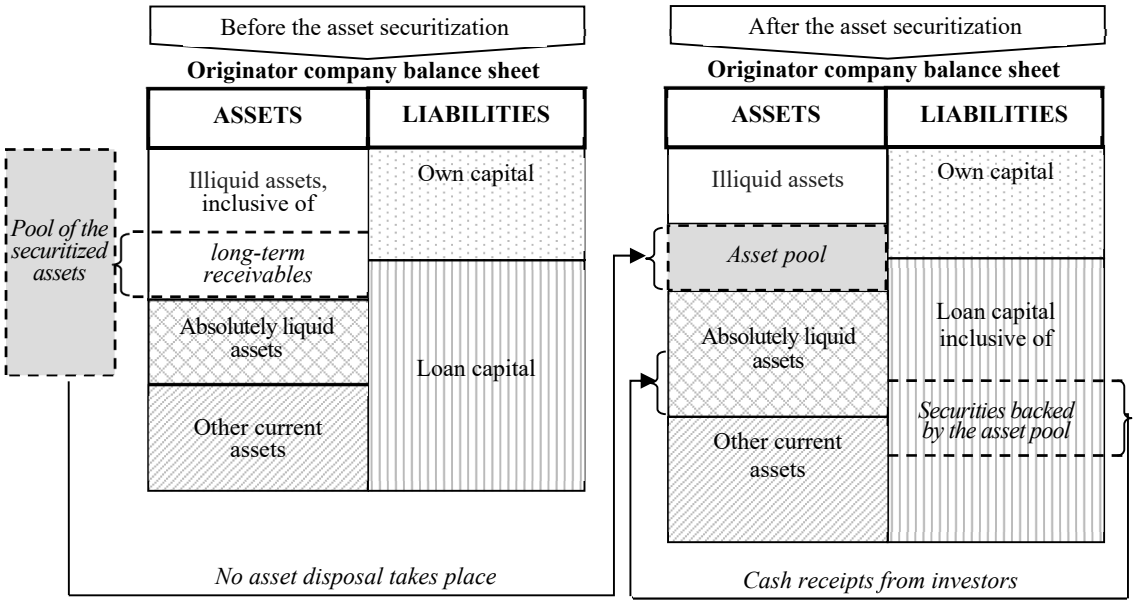


Fig. 5. Influence of the balance-sheet securitization on the balance-sheet indicators.

Consequently, significant changes in the total balance as well as in the structure of its liabilities take place in the process of the balance-sheet securitization when the total balance of the originator company increases by a cash pool attracted as a result of issue of securities backed by its assets. Therefore, value of the attracted capital increase as well as its share within the structure of liabilities.

Consideration of composition and structure of assets of a company should involve such a mention that under the conditions of the classical securitization, assets with low liquidity (for instance, long-term debit debts) are replaced by absolutely liquid assets, i.e. cash raised as a result of the securitized asset sales; in turn, that is followed by the increased share of liquid assets and the increased share of illiquid assets respectively.

Balance-sheet securitization also increases the amount of liquid assets at the expense of the money raised as a result of issue of asset-backed securities by the company. The both cases increase share of liquid assets which factors naturally into the improvement of liquidity indicators on the whole.

Moreover, the mechanism of asset securitization influences positively the amount of financial results as well as profitability indicators. Among other things, under the conditions of balance-sheet securitization, an originator company attracts extra capital and raises financial resources placed at corresponding profitability interest which increases indicators respectively indices of the financial results.

If the classical off-balance sheet asset securitization is meant, then the originator company loses the asset pool which brought regular profits. However, in the majority of cases, the originator services the payments arrived from debtors while receiving the fixed rate of interest from the payments. It should also be mentioned that the classical securitization scheme is applied to place the raised money more profitably to compare with the regular income being gained.

Hence, raising money, any enterprise can use it to implement new relations inclusive of making extra profits in the form of asset interest-security interest margin which, in turn, favours increase in the fund turnover.

Moreover, asset securitization influences directly the process of formation of profits and expenditures since its mechanism involves management of flows of payments followed by payment of premia and fee charges as well as interest payments and interest-taking.

Further consideration of the problem should involve the fact that the weighted-average cost for asset securitization may be lower to compare with the current expenditures for financing attraction through banks or for other loan types. As a matter of fact, the use of the mechanism of off-balance-sheet securitization makes it possible to reduce financing cost at the expense of separation of risk of the originator from asset risk and upon condition that credit quality of the assets being securitized is higher than the credit quality of a balance sheet of the originator on the whole.

In the context of a balance-sheet securitization, issue of the backed debt securities helps attract financial resources at lower interest which reduces respectively the weighted-average cost of loan capital of the originator company.

However, the decreased cost of a loan capital in terms of the increased financial results, when the both asset securitization models are applied, factors into the growth of the company value.

Ye. A. Mitin [28] believes that asset securitization in financial institutions has a direct impact of the financial flows. In turn, the latter can be calculated and forecasted with the specific accuracy, and involved into the financial result; moreover, they can be distributed over interest yields, fee revenues, and management incomes. In this context, the scholar consider interest yields as the excess of interest payments by customers on the securitized assets over cost of investor satisfaction on the issued securities as well as premia to the agreement participants. No extra interest payments arise since the interest charges

are paid on the securitized credits; thus, their distribution has no relation to expenditures by the originator company.

Table 4. Changes in the financial indicators of a company under the influence of its asset securitization.

Direction of analysis	Securitization types	
	Off-balance-sheet (classical) securitization	**Balance-sheet securitization**
Asset valuation potential		
Balance-sheet currency	Minor changes take place per a difference value between balance-sheet value of the securitized assets, and their liquidation value	Increases by a total of issue of securities backed by the relevant assets
Value and structure of assets	Assets with low liquidity are replaced by absolutely liquid assets (i.e. money) which results in the increased share of liquid assets (i.e. cash) and the decreased share of illiquid ones (i.e. long-term debit debts or actual debts)	Asset amount increases by a total of money attracted in the process of issue of asset-backed securities which results in the increased share of liquid assets
Value and structure of liabilities	Minor changes are possible relative to the amount of liabilities at the expense of a difference between the balance-sheet value of the securitized asset pool and sales value. Moreover, the money, raised as a result of the securitization, may be applied to discharge the obligations	Loan capital total increase; hence, its share also increase along with the decrease in the own capital share
Financial potential valuation		
Liquidity indicators	Increase	Increase at the expense of long-term attraction of money
Indicators of financial stability	Remain almost invariable; however, loan funds-own funds ratio may decrease to the extent the money, raised during securitization, can be used to discharge the obligations	Decrease at the expense of the increased loan capital
Valuation of a company development and efficiency		
Indicators of business activity	Negotiability of assets (in particular, regarding money and debit debt) increases. Fulfillment of golden rule in economy is observed	Tendencies of increase and decrease in asset negotiability may happen depending upon the growth of the earned revenue, financial results, and asset value inclusive of the current assets
Indicators of efficiency	Financial results are improved at the expense of placement of the raised finance at the determined return	
	Increase in profitability indicators inclusive of profitability of operational activity, profitability of assets (i.e. increase of financial results in terms of invariable asset value results in the asset profitability growth) etc.	Profitability increases if growth rates of financial results exceed growth rates of relevant expenditures and assets

Consequently, fee revenues resulting from the asset securitization agreements are formed at the expense of originator company performance as a servicing agent; and legal representation of the security issuer in court if loan delinquency happens. Moreover, the originator company generates extra fees owing to the extension of new credits financed by means of the securitization. However, to organize asset securitization process, its initiator should bear sizable administrative expenses: fees paid to rating agencies and consulting agencies in the process of an agreement structuring; sourcing of additional personnel; and implementation of complex information systems.

Rather often, asset securitization is applied to improve capitalization indicators of credit agencies. Hence, in accordance with the current international rules, calculation of indicators of a bank capital adequacy should involve a value of a credit risk in terms of different asset items of the bank balance sheet. Thus, the use of the classical securitization mechanism by banks, feeling lack of own finance, helps them decrease a share of high-risk assets.

Consequently, securitization of bank assets favours the improvement of different financial ratios (e.g. capital turnover; debt-to-equity ratio; return on equity); relaxation in normative requirements relative to minimum amount of capital; and more efficient use of the capital and diversification of financial sources. The financial mechanism helps a bank raise extra profits, at the expense of the increased yield of bank operations, and reduce loan costs. Operational efficiency grows. Since mortgage securities are among the category of low-risk ones coupon rate on them is not high as a rule; even, it can be lower than interest on interbank credit which provides access to cheaper money.

6 Advantages and disadvantages of securitization

Like any implementation of a financial innovation, asset securitization has its own advantages and disadvantages. S. Yu. Salomatina [29], A. A. Bobyl [30] focus on the fact that securitization process helps increase the number of potential investors. S. Yu. Salomatina [29] mentions that securitization improves arbitrage rating of an originator. It means that the securitization initiator may count on higher securitization asset rating to compare with a proper one.

K. M. Isakov [31], D. I. Togonidze [32] and A. A. Bobyl [30] think that in the context of the bank institutions, initiating securitization, the demands, concerning their capital adequacy, turn out to be mitigated through credit risk transfer to the third parties. In elaboration of the abovementioned N. E. Bodrova [33] states that while securitizing, the originator decreases dependence of net assets upon the credit interest fluctuations; improves management of a bank assets and liabilities while decreasing dependence upon the difference in repayment periods in terms of credit transactions and debit ones. Yu. V. Bugel [34] points out at the fact that securitization helps solve a problem of the bank capital adequacy for credit transactions since it

decreases a share of problem loans within a credit portfolio structure thus favouring the decreased amounts of the required reserves to cover the credit risk. Moreover, the attractiveness of securitization tools as money investment objects is as follows: the securities help identify the credit risk level reasonably well; specialized rating agencies do that in the developed countries.

Analysis of the securitization advantages, singled out by different scholars, makes it possible to list the most important of them: finance cost reduction (since issue of the backed securities in the amount of more than fifty million dollars decreases expenditures connected with credit interest payment); risk management (i.e. all the risks are transferred to investors at the expense of payment structuring, and redistribution of liabilities); the improved balance sheet as well as access to liquidity (i.e. long-term assets are written-off from balance sheet of the originator which results in nonliquid asset replacement by cash being absolutely liquid); attraction of additional financing sources to carry on business, and to expand the activities; increasing the number of potential investors; prolongation of financing etc.

On the whole, asset securitization makes it possible to refinance activities of its initiator; to reduce and redistribute risks of the initiator connected with such assets; and manage a level of liquidity of the assets at the expense of changes in their structure. In this context, the methodology provides mutual diversification for the investors as well as for the securitization initiators. Among other things, investors are enabled to invest in assets, inavailable until then, through purchase of high-rating securities. The companies, which proper rating does not correspond to investment one, gain access to a capital market as well as to adequate refinancing (by means of issue of asset-backed securities evaluated by rating agencies as those of higher rating to compare with a primary owner of such assets).

Along with the advantages, the process of asset securitization is not free of disadvantages which make economic agents regard the use of such a financial innovation more carefully. According to the opinion of scholars, heavy expense involved to organize the process is among the most significant disadvantages. In such a way, experts believe that expenditures, connected with securitization, are not less than 3.5% of the cost of the liquidated assets.

I. M. Posokhov [35] and C. Kumpan [36] focus attention on the following fact: since assignation of security rating is paid for the originator, it is the originator that selects such rating agency which is ready to assign the issue the highest possible indicative rating.

A. A. Jobst [22], and K. M. Isakov [31] note that rather often originators form a pool from defective assets at the expense of the use of inefficient methods evaluating the asset pool which makes it possible for originators to ignore conditions of their reliability. I. M. Posokhov [35] emphasizes significant time loss during each stage of securitization formalization. R. J. Hahn [37] and D. I. Togonidze [32] pay attention to inefficient legislation since there are countries having no developed regulatory support for securitization (Ukraine is among those countries).

Table 5. Advantages and disadvantages as for the implementation of asset securitization mechanism.

Agents	Advantages	Disadvantages
Securitization initiator	• Access to capital markets and to adequate financing for those economic agents whose rating cannot correspond to investment one at the expense of asset-backed securities gained by rating agencies a much higher rating (it can be even higher than the issuer rating or country rating); • Hedging and eliminating of risks by means of their redistribution among participants; • Management method of a balance-sheet structure; • Diversification of financial sources; • Decrease in finance cost; • Meeting the criteria of own capital adequacy for bank institutions; • Improvement of economic indicators (i.e. liquidity, financial solvency, negotiability, and profitability); • Increase in the originator company status and its image (i.e. competitive growth); and • Increase in the number of investors	• High cost of an agreement structuring; • Significant amount of the standardized (i.e. homogenous) assets; • Complexity and durability of a period for securitization agreement formalization in particular regarding off-balance sheet one from legal viewpoint (the necessity to enter into numerous contracts)
Investors	• High and stable ratings of asset-backed securities; • Ability to invest in assets differing in risk and profitability; • Low rate of default and bankruptcy of security issuer; • Higher asset-backed security premium is provided to compare with state-owned, bank, and corporative bonds with similar rating	• Low level of monitoring of risks connected with underlying assets; • High rating of asset-backed securities irrespective of their quality; • Ability to form a pool from defective assets
National economy	• More effective risk distribution over the whole financial sector; • Easing of credits for non-legal entities, and higher duration of the credits; • Additional financing sources for real sectors of national economy; • Procurement of funds in terms of possibility of effective (i.e. low-risk) investment for retirement funds and insurance funds as well as for other institutional market players at the expense of transparency of major tranches; • Increase in the investment attractiveness of the country, and integration of the national financial market into the international capital markets	• Securitization of low-quality assets in the uncontrolled amounts favours fictious capital build-up; moreover, it may provoke financial crises

Generally, securitization schemes have its own advantages and disadvantages both for its initiator and investors depending upon distribution of risks and profitability determined with the help of the securitization type (i.e. either balance-sheet securitization or off-balance-sheet one); agreement structure (i.e. the number of tranches and their ratings); and parameters of financial tools being issued (Table 5).

Despite the abovementioned disadvantages, securitization pluses prevail; thus, it often considers as the best innovation of a century past since it involves high development potential both for financial market and for the national economy.

Consequently, securitization effect is of a large-scale microeconomic nature for the reason that the regularized securitization market helps increase efficiency:
- Allocations of financial resources in the economy by means of procurement of retirement, insurance, and other shareholders investing cash in asset-backed securities;
- Distribution of risks over the whole financial sector;
- Multiplier effect results from securitization. Hence, asset securitization became stimulus of economic growth for many developed countries. Namely, the huge funds attracted in the form of asset-backed securities may be used by real economic sector and become powerful stimulus to the accelerated economic development of a country.

7 Securitization in Ukraine

On the Ukrainian financial market only the beginning of the use of securitization as an innovative financing technique is observed, moreover the initiators, in almost all cases, were banking institutions, and mortgage loans were the subject of securitization (Table 6).

Thus, the first securitization transaction was carried out by Privatbank in 2007 worth USD 180 mln. and included about 10 thousand mortgage loans issued in US dollars to individuals in different regions of Ukraine. The mortgage pool was sold to a specially set foreign mortgage company "Ukraine Mortgage Loan Finance No.1", established under the England and Wales' legislation. Debts received investment ratings from international rating companies: the first tranche from Moody's and the second one from Fitch.

A successful example of domestic on-balance sheet securitization was the issue of ordinary mortgage bonds of JSC JSB "Ukrgasbank" in the amount of UAH 50 million in 2007. These bonds were in free circulation on the stock market, they were secured with the rights to claim mortgages previously issued by the bank, and the funds received from borrowers were used to pay income to the bondholders.

The peculiarity of this securitization transaction was that all its members were domestic institutions. The manager of the mortgage coverage was JSCB HVB "Bank Ukraine", and the credit rating "UA BBB +" was assigned to this agreement by the Ukrainian rating agency "Credit Rating". The bonds were issued at an interest rate of 10.5% per year for a period of 3 years. The face value of one bond was UAH 1000. A pool of 393 mortgages was formed by mortgage coverage, which determined a coverage ratio of 89% [38].

Table 6. Statistics of Ukrainian originators' agreements

Name of originator	Year	Amount of issue	Type of securitization	Type of asset	Financial instrument
PJSC CB "Privatbank"	2007	USD 180 million	Off-balance sheet, SPV in London	Mortgage loans	RMBS (Residential mortgage-backed securities)
PJSC JSB "Ukrgasbank"	2007	USD 10 million (UAH 50 million)	On-balance sheet	Mortgage loans	CB (Collateralized Bond)
PJSC CB "Privatbank"	2008	USD 104 million	Off-balance sheet, SPV in London	Car loans	ABS (Asset-Backed Securities)
PJSC CB "Khreshchatyk"	2008	USD 14,7 million (UAH 70 million)	On-balance sheet	Mortgage loans	RMBS
State Mortgage Institution	2008	USD 2,5 million	On-balance sheet	Mortgage loans	CB
PJSC "Leasing IT"	2008	UAH 15 million	Off-balance sheet	Leasing assets	ABS
JSC "Oschadbank"	2013	USD 62 million (UAH 500 million)	On-balance sheet	Mortgage loans	CB

In 2008, PJSC CB "Khreschatyk" made the next synthetic securitization in Ukraine in the amount of UAH 70 million. (USD 14.7 million) with a maturity of 3 years. This issue was regulated by national legislation. The rating agency Fitch Ratings assigned this agreement a rating of "B +", which at the time of the conclusion of the agreement was higher than the rating of the issuer "B -". An increase in the rating of issued bonds relatively to the bank's rating by two points was facilitated by the fact that the security amount was above the legalized minimum of 11.1% as well as the prevailing right of bondholders to the pool of assets. Nevertheless, this rating, both for bonds and for the issuer, is low enough, due to the imbalance of the bank's assets and liabilities by maturity. In its report, Fitch Ratings noted that there was a discrepancy between the cash flow of depreciation of the collateral and the redemption of the secured bonds, which in turn was not offset by the availability of liquid assets or any other mechanism. Thus, as of August 1, 2008, PJSC CB "Khreshchatyk" formed a pool of assets of 403 loans worth UAH 80.6 million. Of these, home loans accounted for 86.6%, but according to domestic legislation, in the formed pool home loans provision should be no more than 75% [39].

The issue of bonds of a securitized leasing portfolio amounted UAH 15,000,000 (when placing bonds with

further increase due to spread reinvestment) in 2008 was significant for the Ukrainian financial market. First of all, it was the first in Ukraine securitization of the assets of a non-bank institution; secondly, this was the first time the classical securitization was conducted in the domestic market, i.e. the issue of bonds was carried out by a specially created domestic company LLC "Leasing IT-SPV", in the Charter of which obligatory attributes specific to classical securitization were predicted (restriction in activities of the issuer, the presence of a special management body, the impossibility of bankruptcy and liquidation of the issuer until the end of settlements with all creditors (bondholders) and confirmation of the appropriate decision by their convocation). The subject of securitization was the financial leasing of IT equipment and the sale of goods by installments for small and medium businesses (SMEs) (10% of the portfolio), as well as individuals (90% of the portfolio).

The issue is structured as a securitization with the real sale of the financial assets of a special company's purpose, with the further possibility of replenishing the asset pool with new leasing agreements. Leasing assets were on a separate balance sheet and were the main security for the issued bonds. At the same time, despite the considerable excess spread of profitability on the portfolio of the transferred leasing assets, the issuer's obligations under the Series A bonds were additionally secured by the guarantee of the originator - PJSC "Leasing IT". Securitization was a revolver, that is, leasing payments were used to finance new agreements to fill the portfolio [40].

The last securitization transaction was carried out in 2013 by JSC "Oschadbank" through a subsidiary mortgage company, the Home Loans Refinancing Agency (HLRA), which issued two series of mortgage bonds under Ukrainian law, for a total amount of UAH 500 million.

Thus, from 2007 to 2013, 7 securitization transactions were conducted, 4 of which were balance sheet financing and 3 were off-balance sheet, with two cross-border securitizations and only one with the creation of a domestic SPV. In addition, in 6 cases, bank assets were securitized, including: 5 times – mortgages and only once – car loans. Securitization of assets of the leasing company was also conducted once.

The main obstacle to the development of the asset securitization market in Ukraine is the lack of adequate legislative support for such a financial mechanism, which further increases the risks for investors. In addition, insufficient homogeneous assets available for securitization; lack of institutional investors interested in investing in securities of domestic companies, as well as lack of qualified personnel with experience or knowledge in entering into such agreements should be mentioned.

In the case of the adoption of legislation that extends securitization to non-mortgage assets, the domestic economy can be significantly revived by the influx of investments in certain industries and projects, especially infrastructure ones. Thus, stimulating the attraction of investments in long-term projects for the development of transport, energy, housing and communal infrastructure as well as social infrastructure can be realized in the form of launching of the infrastructure bonds circulation, for which the fulfillment of obligations is secured by the assets generated by borrowed funds – payments for usage, subscription fee, fees and more. Obviously, the use of securitization of monetary claims in Ukraine will facilitate large-scale financing of the real economy sector, such as house building, local industry, energy conservation and more.

8 Green securitization as the major tool of sustainable investments market development in Ukraine

Sustainable global economy should combine long-term profitability with social justice and environmental care, because global environmental issues have posed new challenges and tasks for society to reduce their negative environmental impact.

"Green" economy is the basis for the implementation of the sustainable development concept based on more efficient resource and energy consumption, reduction of CO2 emissions, reduction of harmful environmental impact and socially integrated society development. As a result, the change in the "trajectory" of the global economy towards sustainable development increasingly determines the desire of governments, TNCs, institutional investors and households to mobilize green investments in low carbon and climate-sustainable infrastructure, the development of renewable energy, conducting industrial and energy modernization, etc. [41].

The large-scale implementation of climate protection projects, the latest resource and nature conservation technologies and environmentally friendly measures to realize the "green" growth of national economies requires strong financial support and, accordingly, requires "reformatting" of current and future investments, and finding alternative financing sources.

Many sustainable investments require long-term loans that diverge from capital and deposits that make up bank balances. In order to provide alternative financing and unleash the balance sheet potential for sustainable assets, illiquid sustainable bank loans can be repackaged to a more liquid format to attract sustainable investors in global capital markets. These issues can be resolved by combining and using sustainable assets through sustainable securitization.

Securitization is envisaged to become one important de-risking instrument that would successfully crowd in private (institutional) investors and scale up sustainable assets. The structural ambition of the securitization for sustainability agenda is to reorganise DEC financial systems from bank-based to capital-markets based models. The structural transformation of financial systems towards securities market-based finance is necessary so that the trillions of institutional investors can find their way into sustainable projects. At country level, it is argued that securitization would pave the way for a more resilient financial system while allowing countries to redirect scarce fiscal resources where most needed [42].

Anna Bak, Associate Director of Securitization at AFME, said: "There is huge potential for green securitization to help expand environmentally sustainable investments in the short term. Green securitization could play an important role in helping to achieve the EU's 2030 climate and energy targets by financing deals and investment in low-carbon assets, which would help to close the investment gap estimated at EUR 180 billion per year. However, there is still more work to do to help make this market more attractive and user-friendly for investors" [43].

Today, the first results of green securitization are evident in a number of the economy sectors the development of which has an impact on the achievement of the Sustainable Development Goals.

LGFAs from Norway, Sweden, Finland and Denmark as well as Dutch bank NWB have all issued green bonds, raising USD 9.5 billion between them since 2010. Three PACE financing providers from California have issued green ABS backed by PACE loans [44].

Solar City (now Tesla Energy) issued the first one in 2013: a USD 54 million deal backed by cash flows from power purchase agreements for the electricity generated by a bundle of residential rooftop PV installations of around 5,000 customers. In total, the company has placed 9 solar ABS deals. In Canada, Northland Power's 2014 ABS is backed by revenue from the 20-year feed-in tariff contract between the company's solar projects and the Ontario grid. FlexiGroup issued the first Australian deal with a green ABS tranche. It refinanced a pool of loans extended to customers for residential rooftop solar. The bond was Certified under the Climate Bonds Standard for Solar assets [44].

Fannie Mae issued USD 26.4 billion of labelled Green MBS in 2017, significantly above the USD 3.5 billion issuance volume achieved in 2016. It is the largest green bond issuer for 2017 [44].

Dutch lender Obvion issued the first green RMBS in 2016. Together with its Green Storm 2017-1, the mortgage lender has now placed USD 1.3 billion of green RMBS. In 2018, National Australia Bank issued an AUD 2 billion RMBS with an AUD 300 million green tranche. All three green issues have been Certified against the Climate Bonds Standard for Low-Carbon Buildings (Residential) [44].

CSAIL, a joint platform of the US operations of Credit Suisse and Natixis, issued the first CMBS deal with green subordinated notes. They are secured on a LEED Platinum certified office building on Wall Street in New York City. But it is China that recorded the first green CMBS – a three-tranche deal secured on a LEED Gold certified office building owned by China Energy Conservation and Environmental Protection Group (CECEP) [44].

Green covered bonds under German Pfandbrief legislation were first issued by BerlinHyp in two EUR500m deals in 2015 and 2016 (USD 1.2 billion in total). Deutsche Hypo followed with a EUR 500 million deal in 2017. In 2018, SpareBank 1 Boligkreditt, the covered bond vehicle of an association of Norwegian savings banks, issued a EUR 1 billion green covered bond with a residential mortgage cover pool [44].

Chinese issuers have issued 11 ABS deals totaling USD 2.4 billion and secured on receivables from wind turbines and other renewable energy equipment leasing, public transport, water and waste management: by far the most diverse sector range among countries with green ABS issuance [44].

Toyota Finance has issued USD 4.6 billion in three green ABS secured against the cash flows from existing car leases and with the proceeds destined to finance new leases and loans exclusively on hybrid and electric vehicles. Using existing "brown" assets to free up capital for more "green" ones is a key component of financing the low-carbon transition [44].

Brazil's innovative securitization instrument has helped farmers and cooperatives secure financing for the production, sale, processing or industrialisation of agricultural products [44].

Credit rights deals have been successful thanks to the competitive loan pricing they offer farmers, the asset-liability match and the tax exemptions for both investors and issuers. In 2016, Suzano Papel issued the first – and so far, only – green CRA ABS of BRL 1 billion (USD 295 million) [44].

The "green" approach global trends, which began to take shape over the last decade in various spheres of public life, are being introduced more and more widely in our country.

In Ukrainian realities, the successful implementation of the "green" economy concept aimed at achieving sustainable development goals can be ensured by the use of green securitization through the collateralized loan obligation mechanism.

Currently most infrastructure projects are funded by bank loans. Infrastructure projects require long term financing which is sub-optimal from a risk weighting perspective; further, most banks are funded on short-term debt or on demand deposits thereby creating a maturity mismatch with longer term projects. Therefore, a mechanism is needed to move project loans from bank balance sheets to bond market investors who are the natural long-term investors in sustainable infrastructure. This mechanism is securitization – the sustainable CLO [45].

Collateralized loan obligations (CLO) are structured financial transactions where certain types of loans, usually highly leveraged syndicated commercial credits, are pooled together and transferred to a trust entity called a SPV. The commercial credits are usually loans issued by financial institutions that are funding high-risk ventures such as leveraged buyouts. The SPV then issues debt to investors to fund the purchase of these loans, and the principal and interest payments that are generated by the loans are paid to investors over time (Fig. 6).

The generic CLO structure envisages the purchase of a pool of loan participations by a Special Purpose Vehicle (SPV) financed by the issuance of tranches of rated securitized bonds (CLO tranches) and unrated "equity". The CLO tranches are rated by credit rating agencies according to their seniority within the capital structure with the senior most tranche considered the least risky and the equity being the riskiest tranche. A broad range of investor groups purchase the tranches based on their

individual risk and return preferences and investment criteria. An asset manager typically manages the underlying pool of loans by constructing a portfolio and optimizing portfolio performance. By transferring the credit risk of the underlying loan portfolio to bond investors via securitization, CLOs have accelerated loan issuance, freed up bank lending capacity and thereby expanded overall credit formation. The same principles can be applied to the sustainable loan market to accelerate credit formation for sustainable projects [45].

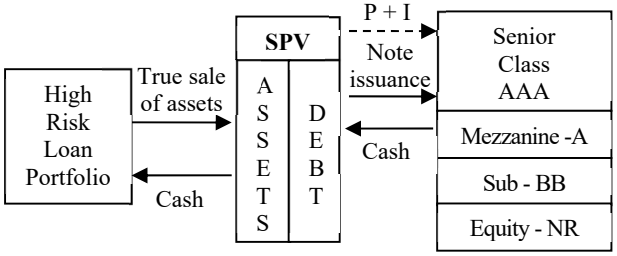


Fig. 6. CLO Example [46].

Sustainable projects can offer institutional investors a range of desirable financial characteristics and funding horizons. For example, the debt repayments from completed projects are typically equivalent to investment grade credit risk and feature stable and predictable cash flows, often with inflation protection due to power price linkage. Wind and solar projects also have an estimated 25-year lifespan with manufacturer warranties and long-term contracts with power purchasers and government support. Assets like these provide the long-term income preferred by many institutional investors and CLOs can provide institutional investors access to these assets while improving the risk-adjusted returns with an optimum liability structure which works through economic cycles [45].

So, due to the securitization of assets, banks not only get rid of bad debt (replacing it with bonds), but also gain the ability to effectively control all debt collection processes (while continuing their service). At the same time, the bank completely eliminates the lengthy burdensome procedures preceding the write-off of bad assets to maturity of assets from the balance sheet. The originator bank is able to repay some of the money in the case of a discounted sale of senior series of subordinated bonds to investors, the amount of which is calculated in the amount of the most probable return on assets. Releasing banks from problem assets is a prerequisite for recovery of bank lending.

Sustainable CLOs will be a pillar of the sustainable securitization revolution. The supply of assets for this product is plentiful and given the vast commitments by financial institutions to increase the quantity of sustainable loans on their books, this is set to continue [1].

We consider that for the development of green securitization in Ukraine, first of all, it is necessary to attach an implicit government guarantee to green finance structures. That would give them a covered bond-type flavour, potentially making the instruments more attractive to investors by lowering the possibility of default. Government backing could stimulate the retail green bond market in particular, where considerable public interest in environmentally-related projects already exists. Other initiatives could include lowering the tax threshold for institutions that use green financing, or offering tax relief on the income from green bonds.

Securitization is rather complex and expensive but highly efficient financial mechanism. In the context of Ukrainian capital market, securitization may become the helpful tool to attract financing and investing, including in the transition to a green economy.

9 Conclusions

Under the conditions of dynamic development of a financial market and economy on the whole, securitization is one of the innovative tools to attract additional finance, to increase liquidity level, to diversify assets, and to minimize risks in the financial markets. It is cheaper refinancing mechanism to compare with other methods of getting funding since emitter can issue securities with higher rating and, consequently, with lower interest by contrast to long-term loan interest.

Lack of adequate legal support for such a financial mechanism is the basic obstacle preventing from the development of asset securitization market in Ukraine, and increasing risks for investors more and more. Still, amounts of homogenous assets, being suited for securitization, are not sufficient; there are no institutional shareholders interested in the investment in the securities of national companies; and there is no qualified personal having either experience or knowledge to draw up such contracts.

At large, balance-sheet securitization as well as off-balance-sheet one influences positively of financial indicators of its initiator. To begin with, asset securitization becomes efficient at the expense of conversion of low-liquidity money claims to highly liquid tools of a capital asset market.

Successful implementation of the concept of a “green” economy aimed at achieving sustainable development goals can be ensured by mobilization of financial resources with the goal of setting the transition to low carbon and resource efficient economic development. We believe that sustainable securitization, in particular green securitization based on the use of the collateralized loan obligation (CLO) mechanism, should become an effective tool for creating new opportunities for attracting financing and development of the domestic sustainable investments market in Ukraine. However, the underlying asset pool may include financial assets such as mortgages on certified buildings, for example, in accordance with LEED, BREEAM, Energy Star or other building codes; mortgage financing to improve energy efficiency; loans or lease payments for electric vehicles; loans or lease payments for solar and wind assets; energy efficiency loans; cash receipts from ESCO contracts or sale of GHG permits etc.

Sustainable securitization based on collateralized loan obligation may be relatively new with a limited number of deals so far, but the diverse range of financial assets and structures used bodes well for the growth of this type

of debt instrument.

In Ukraine, in order to achieve sustainable development goals, the presence of such an instrument in the arsenal of banks and corporations as Sustainable Securitization, is able to fundamentally improve liquidity in the "green" financial market, in particular financing of socially significant risky investments with a long payback period and low profitability or large-scale infrastructure projects aimed at environmental protection.

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Monitoring and modelling of cryptocurrency trend resistance by recurrent and R/S-analysis

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Abstract. The paper focuses on monitoring and modelling of the cryptocurrency market. The application of the chosen research methods is based on the analysis of existing methods and tools of economic and mathematical modelling of time series research on the example of the cryptocurrency market. It is proved that the use of individual methods is not relevant, as they do not give an adequate assessment of the specified market, so a comprehensive approach is the most acceptable. Therefore, monitoring and modelling of some cryptocurrency pairs with different capitalization degree were implemented by fractal and recurrent methods of the financial markets. The daily values of currency pairs for the period from September 2015 to November 2019 were chosen as information basis for monitoring and modelling. The use of *R*/*S* modelling method make it possible to conclude the persistence of time series of the selected cryptocurrencies indicating that the market trends are clearly defined, the currency pair of XRP/USD has the highest level of trend resistance. To compare the obtained results, the comprehensive approach is offered using recurrent diagrams that help to determine the cryptocurrency stability. The results of modelling by the recurrent method show that the most stable cryptocurrencies are the ones with the highest capitalization, namely Bitcoin and Ripple.

1 Introduction

In the context of digitalization and virtualization of the financial sphere, the problem of forecasting the cryptocurrency market dynamically developing in recent years, is of particular importance. The improvement of tools for modelling and forecasting of the cryptocurrency market and risk management are necessary in the context of public distrust of cryptocurrency as an innovative financial asset, and the presence of a number of risks inherent in the cryptocurrency transactions (asset security, hedging complexity, high price volatility, lack of guarantees, legal barriers, the limited use as a means of payment).

National and international researches pay great attention to this problem. Authors [1] point out that the formation and development of the cryptocurrency market are associated with Bitcoin release and blockchain technology that have some spheres of application; and cryptocurrencies are innovative financial asset that attracts investors.

Different approaches and methods are used for modelling and forecasting the cryptocurrency market and forming the investment portfolio. As this market becomes more and more difficult, the potential investors need tools allowing them to form a highly profitable investment portfolio that may include such an asset as cryptocurrency.

To calculate the cryptocurrency market efficiency, paper [2] offers to use Factor Augmented VAR (TVP-FAVAR)-model considering the impact of a large number of variable factors on a dependent variable and allowing to study the dynamics of more than 45 cryptocurrencies. This approach helps to conclude that the periods of high/low uncertainty in the market correspond to strong/weak link. The authors explain the trend by the increased degree of the market uncertainty associated with the process of cryptocurrency price fluctuations. In this situation, they propose to form a dual investment portfolio, the structure of which can be varied by the dynamic hedge ratio and the dynamic weights of the portfolio. Using the ARFIMA-FIGARCH model with two distributions and the modified logarithmic periodogram method, authors [3] studied the stability of eight biggest cryptocurrency markets and made a conclusion that they were unstable, volatile, had the limited trading horizons and time gaps, complicating the process of attracting investors.

Paper [4] proposes to assess the dynamics of the cryptocurrency profitability and stability by the multivariate stochastic model, which allows to calculate the average currency volatility. Its practical application shows the significant impact of such factors as the volatility of the cryptocurrency market on the one hand, and the rapid growth in demand for it on the other.

In their paper [5], researchers use a Lotka-Volterra model with variable intervals to model the number of

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transactions for Bitcoin, Litecoin and Ripple using two- and three-dimensional models that allow them to get high-precision forecast for Bitcoin and satisfactory level for Litecoin and Ripple.

The investigation of cryptocurrency time series using econometric models of stochastic volatility is shown in papers [6, 7]. Alternative one-dimensional dynamic linear and multivariate vector autoregressive models are compared in paper [6]. This approach improves the accuracy of the forecast.

The paper of scientists [8] shows that the use of standard GARCH models can make incorrect VAR and ES forecasts, and thus, lead to inefficient risk management and optimization of the investment portfolio. Therefore, the authors propose to use the method of model building (model complex) of VAR and ES recheck based on a confidence model (MCS) to minimize risks and financial losses.

The traditional method of the cryptocurrency market analysis is technical analysis, but in the conditions of high market volatility, it is reasonable to combine the methods of technical analysis with the methods of economic and mathematical modelling. Thus, authors [9] propose a non-parametric model based on technical analysis as an alternative method of assessment and forecasting of the cryptocurrency market. This approach calculates the forecast values of Bitcoin's profitability through a neural network and indicates the speculative nature of the market.

Traditional methods and modelling do not allow to make accurate forecasts and calculations for the development of the cryptocurrency market being a nonlinear complex economic system and to detect the occurrence of crisis phenomena.

Therefore, it is necessary to use the methods being traditionally inherent in other fields of science. Econophysics has rather powerful methodological apparatus for modelling complex socio-economic systems in modern economic science.

Thus, paper [10] points out that it is necessary to apply comprehensive approach for the forecast considering the nonlinear dynamics and the inherent chaos and fractality of the digital currencies. The authors propose the hybrid model for the forecast based on the neural network of long-term memory (LSTM) and empirical wavelet decomposition (EWT), along with the cuckoo search algorithm (CS) for digital currency time series to obtain more accurate forecast values.

Authors [11] use monofractal analysis to investigate the price volatility in the cryptocurrency market and multifractal fluctuation analysis to test the model for stability.

A strong impulse effect in the Bitcoin and Ethereum markets and a reversal effect for Ripple and EOS at high fluctuations were found as a result of the model implementation. The application of this model will help to form effective alternative strategies for the allocation of assets in the investment portfolio.

Ukrainian scientists [12] propose the procedure for determining the normalized economic coordinates, economic mass and heterogeneous economic time, based on the basic concepts of general theory of relativity and relativistic quantum mechanics. They are based on the analysis of time series describing socio-economic phenomena and economic interpretation of uncertainty by Heisenberg. The authors confirm that the economic mass of the time series can be an indicator of crisis phenomena.

Therefore, a combination use of different methods of economic and mathematical modelling of the cryptocurrency market allows to increase the accuracy of forecasting, to identify the indicators of crisis phenomena, to analyze the degree of volatility and risk of both individual cryptocurrencies and their pairs.

2 Research methodology

2.1 *R/S*-analysis

R/S-analysis was first proposed by B. Mandelbrot [13] and is based on H. Hurst hydrological studies. According to Hurst, the essence of fractal analysis for time series is to process the structure of a series that reflects a certain process and demonstrates a quantitative degree of chance. In paper [14], this approach was proposed to quantify the nature of self-affine structures.

The method of *R/S*-analysis allows calculating the parameter of self-similarity H, which measures the intensity of long-term dependencies in a time series. This metric is based on the analysis of the parameter range and the standard deviation.

Here is an algorithm for *R/S*-analysis. Suppose that the time series $y = \{y_i\}$, $i = 1, 2, \ldots, N$ is given, which must be led to "logarithmic returns". The resulting sequence is divided into initial segments $y = y_1, y_2, \ldots, y_N$.

(i) The average value and standard deviation of S_n are calculated for each segment.

(ii) The cumulative deviation is calculated:

$$x_{t,N} = \sum_{i=1}^{t}(y_i - M_N), \quad (1)$$

where y_i – increase in a year i, M_N – average, y_i for N periods.

(iii) Range is determined:

$$R(N) = \max(x_{t,N}) - \min(x_{t,N}), \quad (2)$$

where $R(N)$ – deviation range $x_{t,N}$, $\max(x_{t,N})$ – maximum value for $x_{t,N}$, $\min(x_{t,N})$ – minimum value for $x_{t,N}$.

(iv) From the ratio

$$R/S = (aN)^H, \quad (3)$$

where R/S – normalized range, N – observation number, a – constant, the Hurst exponent H is derived.

By the value of the Hurst coefficient, we can identify time series and draw conclusions about the minimum forecast of these series behaviour:

(i) $H = 0.5$ – the sequence is white noise; the time series is random. The future values of this series are independent of the previous ones. System status is random walk;

(ii) $0 < H < 0.5$ – anti-persistent or ergodic time series (pink noise), i.e. a series characterized by the so-called "return to average": if there is a decline in the indicator in

the studied system over a period of time, an increase should be expected in the next period. The closer H is to 0, the more variable the series is. These changes happen quickly, often, but they are small. Note that such processes are few in reality. System status – flute;

(iii) $0.5 < H < 1$ – persistent or trend resistant time series (black noise, Brownian motion). The time series is characterized by the effect of long-term memory. If the series is growing, it is likely to continue to grow. If it falls today, a decline should be expected tomorrow. The closer the value of H is to 1, the more trend resistance is. The closer the value of N is to 0.5, the noisier the number will be. System status is a trend.

2.2 Recurrent diagrams

Recurrent diagrams as a graphical tool are proposed in [15]. They are based on the theory of phase reconstruction of space. Many processes in nature are known to have periodical character, i.e. recurrent behaviour. Moreover, the recurrence (repeatability) of states in the meaning of passing a further trajectory close enough to the previous one is a fundamental property of dissipative dynamic systems [16]. A. Poincare discovered this property and formulated it in the form of a "recurrence theorem": if the system reduces its dynamics to a limited subset of the phase space, it (the system) is almost certain, i.e., with a probability, almost equals to 1, as close to any initially set mode as possible [17].

The content of this theorem is that a complex dynamical system can deviate from its state by the exponential law due to the smallest perturbation, but after a while the system will seek to return to the initial state and undergo similar stages of evolution.

J. P. Eckmann and co-authors [15] propose a method of displaying m – the measured phase trajectory of system states $\vec{x}(t)$ of N length, on a two-dimensional square binary matrix of $N \times N$ size, in which 1 (black point) corresponds to the repetition of the state at some time i at some other time j; and both coordinate axes are time axes. This display was called a recurrent diagram because it captures information about the recurrent behaviour of the system (Table 1).

Formally, the recurrent diagram can be expressed by the matrix:

$$R_{i,j}^{m,\varepsilon_i} = \Theta(\varepsilon_i - \left\|\vec{x}_i - \vec{x}_j\right\|), \cdot\vec{x} \in \Re^m, \cdot i, j = 1,...,N \ , (4)$$

where N – the number of measured points, $\overrightarrow{x_i}, \varepsilon_i$ – the size of neighbourhood of point $\vec{x}$ at a moment i, $\|\cdot\|$ – normalization operator and $\Theta(\cdot)$– the Heaviside function.

Since $R_{i,j} = 1 \ (i = 1, \dots, N)$ by definition, the recurrent diagram always contains a diagonal line consisting of black points – an identity line at an angle of $\pi/4$ to the coordinate axes. A separate recurrent point does not provide useful information about states in time i and j. Only the whole set of recurrent points allows to restore the properties of the system.

Visual assessment of recurrent diagrams can give an idea of the nature of the processes occurring in the system under study and conclude that the state of change is rapidly due to critical phenomena.

Table 1. Typical samples of recurrent diagrams and their interpretation [16].

Sample	Interpretation
Homogeneous	Stationary process
Extinction in the upper left and lower rights corners	Non-stationary data; the process contains trend or drift
Destruction (white stripes)	Non-stationary data; some conditions are exceptional or far from normal; transitions may have occurred
Periodic / quasiperiodic samples	Cyclicity in the process; the time distance between periodic samples (e.g. lines) corresponds to the period; the difference in distances between long diagonal lines shows the quasi-periodicity of the process
Diagonal lines (orthogonal to the main diagonal)	The evolution of a state is similar to time difference
Vertical / horizontal lines (clusters)	Some states do not change or change over time; sign of laminar states
Long inclined structural lines	The evolution of states is similar in different periods, but at different speeds; the dynamics of systems could change

3 Research findings

Six cryptocurrencies were selected for the study; they differ in cryptographic (software) code. They are Bitcoin (BTC, forks), Namecoin (NMC, forks), Ethereum (ETN, crypto 2.0 – the second-generation cryptocurrencies), BitShares (BTS, crypto 2.0 – the second-generation cryptocurrencies), Ripple (XRP, code from scratch), Nextcoin (NXT, code from scratch). Bitcoin, Ethereum, Ripple cryptocurrencies are at the top of their capitalization ratings. Other cryptocurrencies used in the paper are less capitalized, but they are within 450 positions in the ranking. The study covers the time span from September 2015 to November 2019. The calculations were made in the MatLab environment based data [18].

Here are the estimated values of the Hurst indicator for cryptocurrency pairs (Table 2).

Table 2. Results of the Hurst coefficient calculations.

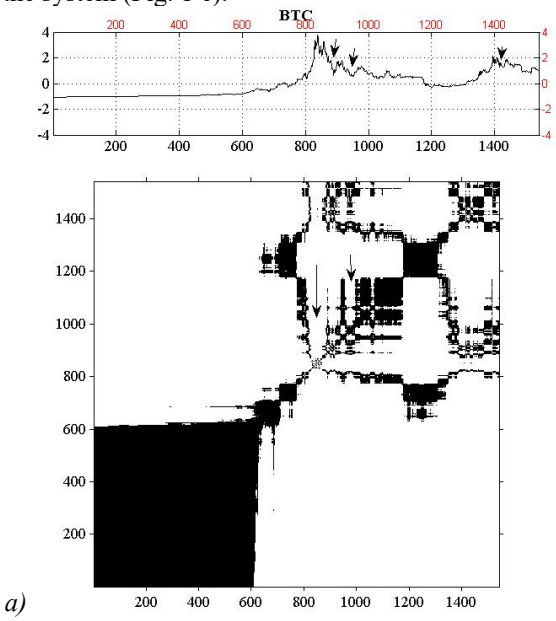
Currency pair	Hurst coefficient value (H)
XRP/USD	0.744
ETH/USD	0.708
NXT/USD	0.692
BTS/USD	0.678
BTC/USD	0.637
NMC/USD	0.571

According to the obtained values of the Hurst coefficient (Table 2), we can conclude that the time series of these cryptocurrencies are persistent, i.e. the markets show clear trends, since the values of the Hurst coefficient are in the range of 0.5 to 1. The XRP/USD currency pair

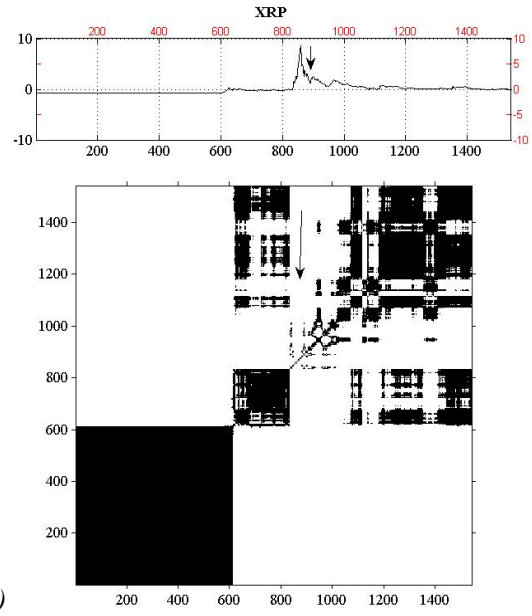
has the highest H = 0.74 meaning that it has the highest trend resistance among other currency pairs. In our view, the legal recognition of this cryptocurrency at the state level is an influential factor. It is one of the most popular cryptocurrencies today. It was created to accelerate transactions and currency conversion; it is also one of the cryptocurrencies used to support the technology of the future "Internet of Things".

Table 2 shows that the minimum value H=0.571 has the NMC/USD currency pair indicating its least trend resistance. This cryptocurrency has one of the lowest levels of capitalization among the cryptocurrencies under consideration.

Fig. 1 shows the results of calculations in the form of recurrent maps. The analysis of recurrent diagram reveals common features in distributions of both topology and structure of diagrams. The dark areas of the diagram indicate that the series is relatively stable. It should be noted that the irregular appearance of black and white zones indicates the irregularity of the processes occurring in the system (Fig. 1 e).



a)



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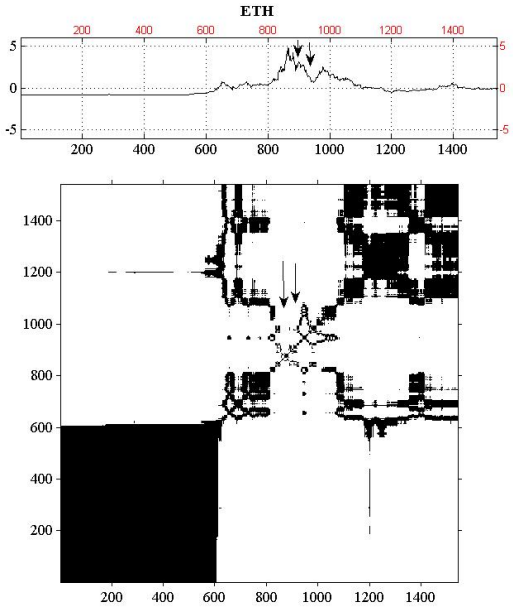
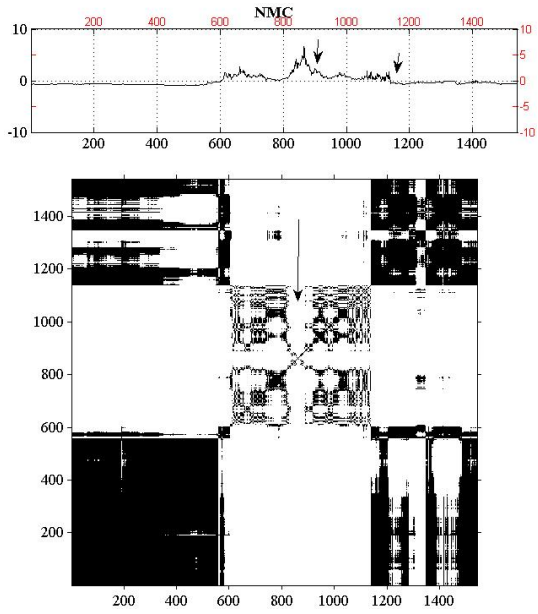
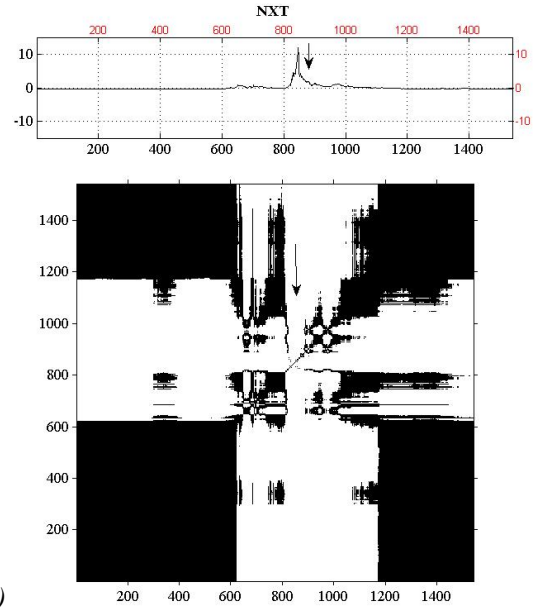


c)



d)



e)

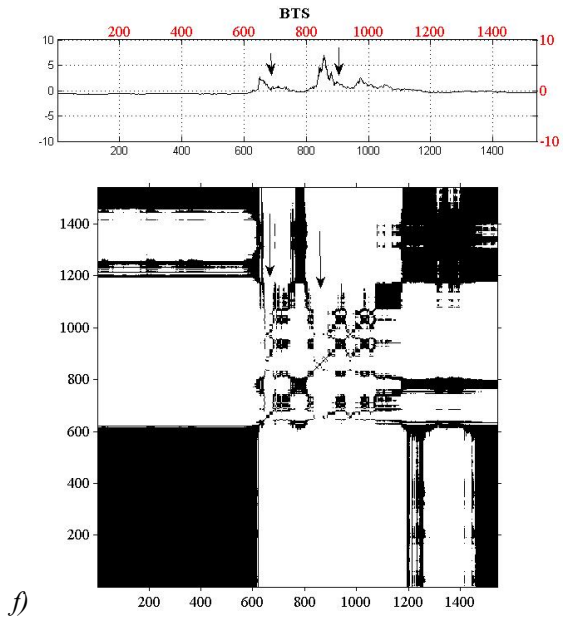


Fig. 1. Recurrent time series diagrams of Bitcoin (a), Ripple (b), Ethereum (c), Namecoin (d), Nextcoin (e), BitShares (f).

At the same time, we can state that the points are mostly located along the diagonal line for the series having higher values of the Hurst coefficient. The recurrent points fill a larger region of phase space for series with a small Hurst value.

Fig. 1 shows that in the neighbourhood of point 900 (2018 crisis), recurrent diagrams for cryptocurrency time series are starting to change. For the studied currency pairs, we observe the appearance of white areas and stripes during a crisis in the neighbourhood of point 900. It can also be noted that the recurrent diagrams for more capitalized currencies is similar in nature, especially for the recurrent diagrams of Bitcoin cryptocurrencies (Fig. 1 a), Ripple (Fig. 1 b), and Ethereum (Fig. 1 c).

The recurrent diagrams are somewhat different for the time series of Nextcoin cryptocurrencies (Fig. 1 e), and BitShares (Fig. 1 f). The recurrent diagrams of these cryptocurrencies are characterized by frequent changes of white and dark areas. Concerning the time series of Namecoin cryptocurrency (Fig. 1d), its recurrent diagram is similar to the recurrent diagrams of the most capitalized cryptocurrencies. However, there are white spots and lines in the beginning of 2019 (1200 point). It shows a certain crisis situation of these cryptocurrencies during that period.

4 Conclusions

We can conclude based on the results of the cryptocurrency market research that cryptocurrencies have long-term potential and prospects in today's globalized economy being subject to crisis.

The *R*/*S*-analysis shows that trend-resistant cryptocurrencies are the most capitalized in times of crisis. Ripple, the cryptocurrency being the official payment instrument in Japan since 2017, is marked by its stability.

A comprehensive approach to monitoring and modelling the cryptocurrency market using recurrent diagrams provides information on the temporal correlation of phase space points and determines the status and trends of the cryptocurrency markets with sufficient accuracy regardless of their classification. The analysis of the cryptocurrency market in the paper leads to the conclusion that the state of currencies on it is quite stable at the current date.

The proposed methodology for monitoring and modelling the cryptocurrency market is of practical importance as it will allow potential investors to form a profitable portfolio with a high level of reliability and stability over time.

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Recurrence based entropies for sustainability indices

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Abstract. The work is devoted to a comparative analysis complexity of traditional stock market indices and social responsible indices in the example Dow Jones Sustainability Indices and Dow Jones Industrial Average. As measures of complexity, the entropies of various recurrence indicators are chosen – the entropy of the diagonal lines of the recurrence diagram, recurrence probability density entropy and recurrence entropy. It is shown that these measures make it possible to establish that the socially responsive Dow Jones index is more complex. A comprehensive assessment of complexity reveals the nature of the effectiveness of social responsible indices and opens up new opportunities for investor risk management.

1 Introduction

Current economic trends have convincingly demonstrated that *green development* is a necessary condition for *sustainable development*, which is essential for a better life in the future [1]. Economists have described climate change as a global market failure estimating that without action, the rising overall costs of climate could result to losing at least 5% of global GDP each year. A growing number of financial institutions is joining in a constructive dialogue on the relation between economic development, environmental protection and sustainable development. Financial institutions, including banks, insurers, and investors, work with the United Nations Environment Programme – Finance Initiative to better understand environmental, social and governance challenges, why they matter to finance, and how to take steps to address them [2].

The availability of stock indexes based on sustainability screening makes increasingly viable for institutional investors the transition to a portfolio based on a Socially Responsible Investment (SRI) benchmark at relatively low cost.

The 2008 subprime crisis and increased social awareness have led to a growing interest in topics related to socially responsible investment. SRI is a long-term investment that integrates environmental, social and corporate governance criteria (ESG). According to the Global Sustainable Investment Alliance (GSIA), SRI reached 24 trillion euro's in 2016, registering a growth of 25.2% between 2014 and 2016. So, green and sustainable finance is more important nowadays than ever before [3].

This increased social interest coincides with international initiatives aimed at developing environmental and social policies on sustainable finance issues, such as the Action Plan on sustainable finance adopted by the European Commission in March 2018. This plan has three main objectives:
(i) to redirect capital flows towards sustainable investment to achieve sustainable and inclusive growth,
(ii) to manage financial risks stemming from climate change, environmental degradation and social issues, and
(iii) to foster transparency and long-termism in financial and economic activity. Therefore, the main purpose is to enhance the role of finance and to build an economy that enables the goals of the Paris Agreement (2015) and the EU for sustainable development to be reached [4].

The Dow Jones Sustainability World Index comprises global sustainability leaders as identified by SAM. It represents the top 10% of the largest 2,500 companies in the S&P Global BMI based on long-term economic, environmental and social criteria [5]. Founded in 1995, RobecoSAM is an investment specialist focused exclusively on Sustainability Investing [6].

The S&P Global Broad Market Index (BMI) is the only global index suite with a transparent, modular structure that has been fully float adjusted since 1989. This comprehensive, rules-based index series employs a transparent and consistent methodology across all countries and includes more than 11,000 stocks from 25 developed and 25 emerging markets [7]. The SAM Corporate Sustainability Assessment (CSA), established by RobecoSAM, is now issued by S&P Global. RobecoSAM, an asset manager focused entirely on sustainable investing, established the CSA in 1999. The CSA has become the basis for numerous S&P ESG Indices over the last two decades attracting billions of USD in assets. In addition, S&P Global acquired RobecoSAM's ESG Ratings and Benchmarking businesses which operate out of S&P Global Switzerland.

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SAM is a registered trademark of S&P Global. ESG (environmental, social and governance) is a generic term used in capital markets and used by investors to evaluate corporate behaviour and to determine the future financial performance of companies. In the conditions of a wide variety of sustainable development indices, it is extremely important for investors to have a comparative characteristic of traditional indices with sustainable development indices obtained by *quantitative methods*. At the same time, the set of tools of modern financial analysis took shape in a separate rapidly growing applied science – *fintech*. Financial technology ("fintech") is emerging as a core disruptor of every aspect of today's financial system. Fintech covers everything from mobile payment platforms to high-frequency trading (HFT), and from crowdfunding and virtual currencies to blockchain. In combination, such forceful innovations will threaten the viability of today's financial sector business models, and indeed the effectiveness of current policies, regulations and norms that have shaped modern finance. The use of financial technology innovations is of course not new – but a step change is now expected with the novel application of a number of technologies in combination, notably involving blockchain, the Internet of things (IoT) and artificial intelligence (AI) [8]. The widespread introduction of fintech makes it possible to talk about *green finance* as a strategy for financial sector and broader sustainable development that is relevant around the world [9-12]. Green economy, green finance and green development are the peculiar coordinates of the phase space in which today it is generally accepted to evaluate the sustainable development of world civilization.

Our research structured as follows. Section 2 contains a brief description of socially responsive indexes and an analysis of previous work on a comparative quantitative analysis of this variety of indices. Section 3 describes algorithms for constructing entropy measures of complexity based on the properties of the recurrence of a phase portrait of a time series. Entropy measures introduced are calculated on the basis of the DJIA and DJSI indices. Section 4 summarizes the results obtained and indicates the direction of subsequent studies.

2 Social responsible indices

In the last 20-25 years, a huge number of social responsible or sustainability indices have been created and their number continues to grow [13, 14]. Briefly consider the most commonly used.

The Dow Jones Sustainability Indices (DJSI) are a family of best-in-class benchmarks for investors who have recognized that sustainable business practices are critical to generating long-term shareholder value and who wish to reflect their sustainability convictions in their investment portfolios (http://www.sustainability-indices.com/). The family was launched in 1999 as the first global sustainability benchmark and tracks the stock performance of the world's leading companies in terms of economic, environmental and social criteria. Dow Jones Sustainability World Index, the most important global stock market valuation index of corporate social responsibility.

FTSE4Good was created by the FTSE Group to facilitate investments in companies that meet globally recognised corporate responsibility standards and constitutes an important reference point for the establishment of benchmarks and ethical portfolios. Companies in the FTSE4Good Index have met stringent environmental, social and governance criteria, and are therefore potentially better positioned to capitalise on the benefits of responsible business practice (http://www.ftse.com/).

MSCI is a leading provider of investment decision support tools to investor globally, including asset managers, banks, hedge funds and pension funds. MSCI Global Sustainability Indexes include companies with high ESG ratings relative to their sector peers (http://www.msci.com/).

CDP (formerly the "Carbon Disclosure Project") is one of the world's leading not-for-profit climate change organizations, assessing transparency in the disclosure of information on climate change and greenhouse gas emissions, as well as in the management of water resources (http://www.cdp.net/).

United Nations Global Compact 100 ("GC 100"), a global stock index developed and released by the UN Global Compact in partnership with the research firm Sustainalytics (https://www.unglobalcompact.org/). The index lists the 100 companies which globally outstand for executive leadership commitment and consistent baseline profitability, as well as their adherence to the Global Compact's ten principles, on human rights, labour, environment and anti-corruption issues.

STOXX Global ESG Leaders Indices, a group of indices based on a fully transparent selection process of the performance, in terms of sustainability, of 1,800 companies worldwide (http://www.stoxx.com/). The ratings are calculated for three sub-areas – environmental, social and governance – and are then combined to form the overall index. The indices are managed by STOXX, the owner of some of the most important international stock indices, such as the STOXX50.

In our work, we will carry out a comparative analysis of the index DJSI [15] with its classic and traditional counterpart – the index Dow Jones Industrial Average (DJIA) [16].

2.1 State of the art

In a comparative analysis of structural and dynamic properties of traditional stock market indices and social responsible indices, descriptive statistics methods are used in most works [17-20].

Descriptive statistics (mean, maximum, minimum and standard deviation) of the financial information required to apply the Ohlson [17] valuation model reviewed in [18]. They were examining whether sustainability leadership – proxied by membership of the Dow Jones Sustainability Index Europe – is value relevant for investors on the 10 major European stock markets over

the 2001–2013 period. Our overall results reveal that there exist significant differences across markets.

The article [19] analyzes rate-of-return and risk related to investments in socially responsible and conventional country indices. The socially responsible indices are the DJSI Korea, DJSI US and Respect Index, and the corresponding conventional country indices are the Korea Stock Exchange Composite KOSPI, Dow Jones Industrial Average and WIG20TR. Shown, that conclude that investing in the analyzed SRI indices do not yield systematically better results than investing in the respective conventional indices, both in terms of neoclassical risk and return rate.

The authors [20] examined sustainable investments returns predictability based on the US DJSI and a wide set of uncertainty and financial distress indicators for the period January 2002 to December 2014. They employ a novel nonparametric causality-in-quantile approach that captures non-linearities in returns distribution. Based on our findings we conclude that the aggregate Economic Policy Uncertainty (EPU) indicator and some components have predictive ability for real returns of the US sustainable investments index. Paper [21] explores the relationship between sustainability performance and financial performance by looking at the impact of sustainability index changes on the market value of a company. The author has studied the price effects of changes in the DJSI and FTSE4Good Index. He failed to observe statistically significant positive abnormal returns for companies being added to a sustainability index. On the opposite he finds negative abnormal returns for companies being deleted from the FTSE, however not in the case of the DJSI. This can be explained by studying the volume effects and the behavior of investment managers.

However, the first works appeared using more modern methods of analysis, using the achievements of nonlinear dynamical systems and complexity theory [22-27]. The authors [22] constructed a sustainable regional green economy development index system from five aspects; economic, social, technological, resources, and environmental; using DPSIR (drivers, pressures, state, impact, response model) and entropy-TOPSIS (technique for order preference by similarity to an ideal solution)-coupling coordination to horizontally and vertically quantitatively analyze the sustainable green economy development. The model was verified by the actual situation of green economy development in Shandong Province from 2010 to 2016, which confirmed the feasibility of the method.

A sustainable development capacity measure model for Sichuan Province was established by applying the information entropy calculation principle and the Brusselator principle [23]. Each subsystem and entropy change in a calendar year in Sichuan Province was analyzed to evaluate Sichuan Province's sustainable development capacity. It was found that the established model could effectively show actual changes in sustainable development levels through the entropy change reaction system, at the same time this model could clearly demonstrate how those forty-six indicators from the three subsystems impact on the regional sustainable development, which could make up for the lack of sustainable development research.

A similar approach is implemented to measure the tourist attractiveness of the region [24]. And in work [25] information and entropy theory used for the sustainability of coupled human and natural systems.

Authors' [26] used R/S analysis to calculate the Hurst exponent as a measure of persistence (efficiency of traditional stock market indices and social responsible stock market indices). The presence of persistence was evidence in favor of less efficiency. According to empirical results, SRI has lower efficiency, in particular the Dow Jones Sustainability Index. Lower efficiency was also observed in the emerging markets with a responsible investment segment, compared to the traditional stock market indices.

In paper [27] authors suggest three new indicators based on an engineering approach of irreversibility. They allow evaluating both the technological level and the environmental impact of the production processes and the socio-economic conditions of the countries. Indeed, they are based on the energy analysis and on the irreversible thermodynamic approach, in order to evaluate the inefficiency both of the process and of the production systems, and the related consequences. Three applications are summarized in order to highlight the possible interest from different scientists and researchers in engineering, economy, etc., in order to develop sustainable approaches and policies for decision makers.

3 Comparative analysis complexity of traditional stock market indices and social responsible indices

As an analysis of previous studies shows, there is no systematic comparative analysis of traditional and persistent indexes, which is primarily due to the use of uninformative methods. In a series of recent works [28-31], we have demonstrated the possibility of using the theory of complex systems and a set of developed analysis tools to calculate the corresponding measures of system complexity. These complexity measures make it possible to differentiate systems according to the degree of their functionality, to identify and prevent critical and crisis phenomena.

As an example of such a quantitative measure, we give the well-known entropy measure of complexity - approximate entropy [32]. For the daily DJSI and DJIA time series $S(t)$ for the period 03 January 1994 – 07 February 2020 (Figure 1), the approximate entropy calculated by the sliding window algorithm is shown in Fig. 2.

The returns over some time scale Δt is defined as the forward changes in the logarithm of $S(t)$ $G(t) \equiv \ln S(t+\Delta t)/\ln S(t)$ Since different indices have different levels of variability (standard deviations), we will determine standardized returns $g(t) \equiv [G(t) - \langle G \rangle]/\sigma$, where $\sigma \equiv \sqrt{\langle G^2 \rangle - \langle G \rangle^2}$ is the standard deviation G, and $\langle ... \rangle$ denotes the average over the time period under study.

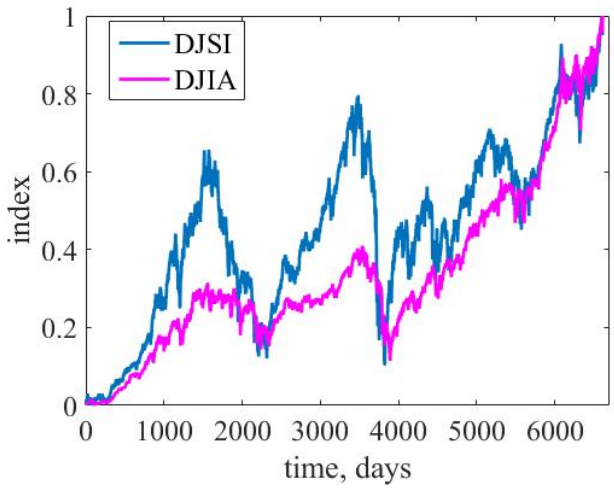


Fig. 1. Comparative dynamics of daily values of stock indices DJSI and DJIA.

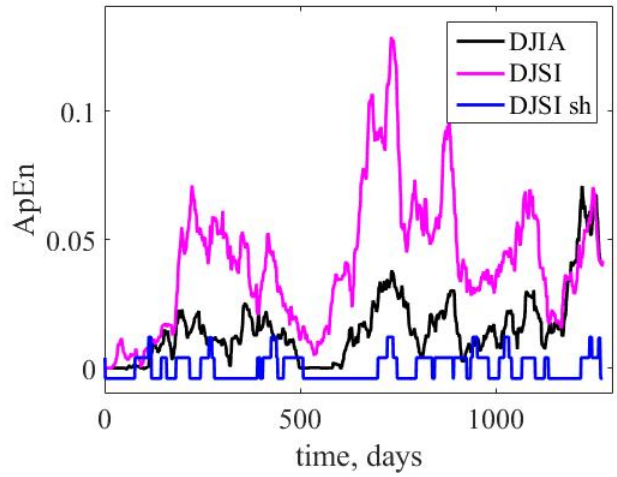


Fig. 2. The approximate entropy (ApEn) indices DJIA and DJSI calculated for a window of 250 days in increments of 5 days. DJSI sh represents the entropy of the shuffled (sh) time series.

The use of such complexity measures has become relevant in view of the fact that time series of similar complexity are statistically almost indistinguishable. For example, the distribution of the normalized returns of the indices presented in Fig. 1 is almost identical (Fig. 3), while the entropy measures solve the problem.

In this paper, recurrence properties, for concreteness, entropy indicators are used as measures of the complexity of stock indices.

3.1 The family of recurrence entropies

In recent years, new quantifiers of nonlinear time series analysis have appeared based on properties of phasespace recurrences [33]. According to stochastic extensions to Taken's embedding theorems the embedding of a time series in phase space can be carried out by forming time-delayed vectors

$$\vec{X}_n = [x_n, x_{n+\tau}, x_{n+2\tau}, ..., x_{n+(M-1)\tau}] \qquad (1)$$

for each value x_n in the time series, where M is the embedding dimension, and τ is the embedding delay. These parameters are obtained by systematic search for the optimal set. Figure 4 shows a phase portraits of the DJSI index and its normalized logarithmic returns.

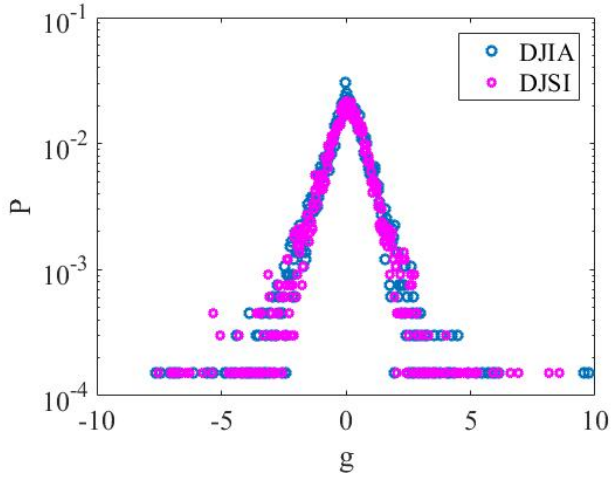


Fig. 3. Distribution functions P of the normalized profitability indices DJIA and DJSI.

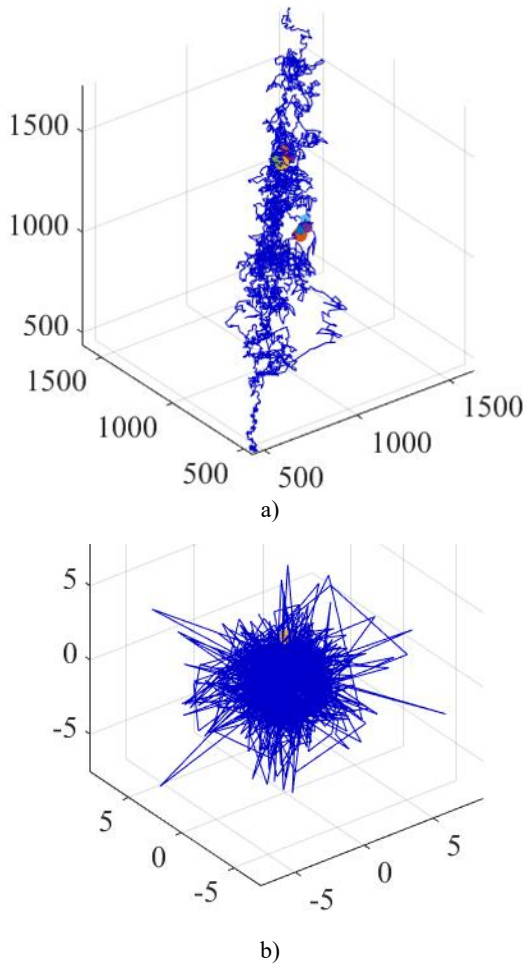


Fig. 4. A phase portraits of the DJSI index (a) and its normalized logarithmic returns (b).

A modern visualization method known as recurrence plots (RP), and is constructed from the recurrence matrix $\vec{R}_{ij}$ defined as

$$\vec{R}_{ij}(\varepsilon) = \Theta(\varepsilon - \|x_i - x_j\|), \qquad i, j = 1, 2, ..., M, \qquad (2)$$

where x_i and x_j represent the dynamical state at time i and j, Θ is the Heaviside function, M is length of the analyzed time series and ε is the threshold or vicinity parameter, consisting of a maximum distance between two points in a trajectory such that both points can be considered recurrent to each other.

The graphical representation of the RP allows to deriving qualitative characterizations of the dynamical systems. For the quantitative description of the dynamics, the small-scale patterns in the RP can be used, such as diagonal and vertical lines. The histograms of the lengths of these lines are the base of the recurrence quantification analysis [33]. Based on the statistical properties of the recurrence plot, a large number of quantifiers have been developed to analyze details of a RP. Many of them, deal with statistical properties such as mean size, maximum size, frequency of occurrence of diagonal, vertical or horizontal recurrence lines. An important class of recurrence quantifiers is those that try to capture the level of complexity of a signal. As an example, we mention the already known entropy based on diagonal lines statistics. This quantity has been correlated with others dynamical quantifiers as, for example, the largest Lyapunov exponent, since both capture properties of the complexity level of the dynamics. The vertical (horizontal) lines in R_{ij} are associated to laminar states, common in intermittent dynamics [33].

3.1.1 Entropy of the diagonal lines

It was reported the use of the distribution of diagonal lines $P(l)$ for a different quantifier of recurrences, based on the Shannon entropy [33]. If we choose a distribution of diagonals

$$p(l) = P(l) / \sum_{l=1}^{K} P(l) \qquad (3)$$

for K the maximum length of the diagonal lines, then we get one of the known quantitative indicators of recurrence analysis:

$$ENTR = -\sum_{l=l_{\min}}^{l=l_{\max}} p(l) \ln p(l) \qquad (4)$$

However, as follows from the analysis of entropy indicators, the results are not always possible to coordinate with the proposed models.

To the pleasure of the researchers, it turned out that depending on the technology of using the properties of the recurrence of the phase space, different types of recurrence entropies are distinguished [33].

The following results are obtained for windows of 500 days in increments of 5 days.

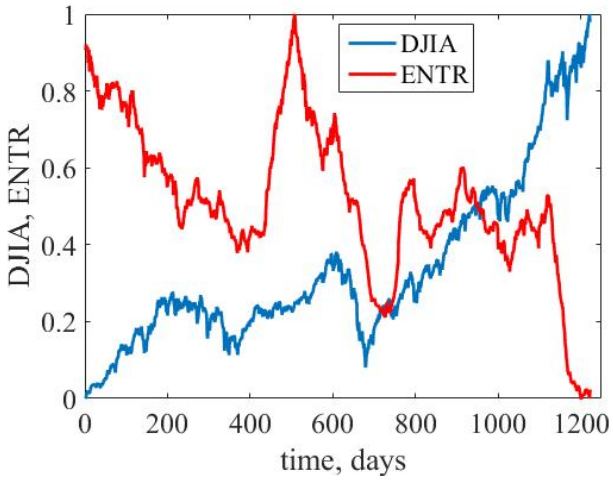
The entropy of the diagonal lines for the time series of the DJIA and DJSI is presented in Figure 5.

3.1.2 Recurrence probability density entropy

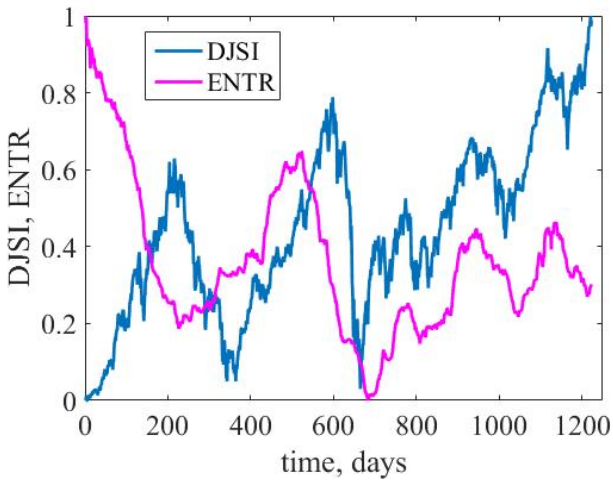
Recurrence probability (or period) density entropy (rpde) is useful for characterising the extent to which a time series repeats the same sequence [34]. Around each point x_n in the phase space, an ε-neighbourhood (an m-dimensional ball with this radius) is formed, and every time the time series returns to this ball, after having left it, the time difference T between successive returns is recorded in a histogram. This histogram is normalised to sum to unity, to form an estimate of the recurrence period density function $P(T)$. The normalised entropy of this density

$$H_{norm} = -(\ln T_{\max})^{-1} \sum_{t=1}^{T_{\max}} P(t) \ln P(t) \qquad (5)$$

is the rpde value, where $T_{\max}$ is the largest recurrence value.



a)



b)

Fig. 5. The entropy of the diagonal lines for the time series of the DJIA (a) and DJSI (b).

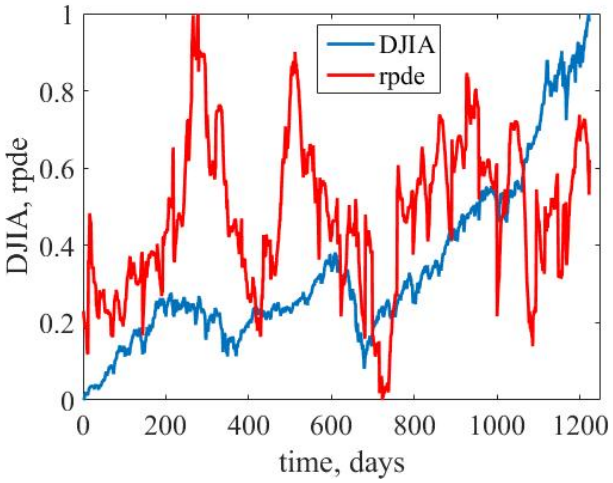
The window dynamics of recurrence probability density entropy for the time series of the DJIA and DJSI are given in Figure 6.

3.1.3 Recurrence entropy

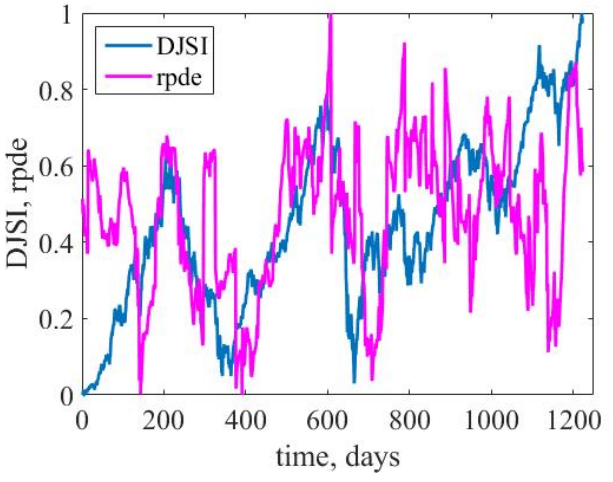
Recent work [35] presents a slightly different technique

for calculating recurrent entropy using a novel way to extract information from the recurrence matrix. The authors have generalize these concepts recurrence defining recurrence microstates $F(\varepsilon)$ as all possible cross-recurrence states among two randomly selected short sequences of N consecutive points in a K length time series, namely $F(\varepsilon)$ are $N\times N$ small binary matrices. The total number of microstates for a given N is $N_{ms} = 2^{N^2}$. The microstates are populated by $\bar{N}$ random samples obtained from the recurrence matrix such that $\bar{N} = \sum_{i=1}^{N_{ms}} n_i$, where n_i is the number of times that a microstate i is observed. For $P_i = n_i / \bar{N}$, the probability related to the microstate *i*, we define an entropy of the RP associated with the probabilities of occurrence of a microstate as

$$S(N_{ms}) = \sum_{i=1}^{N_{ms}} P_i \ln P_i \qquad (6)$$



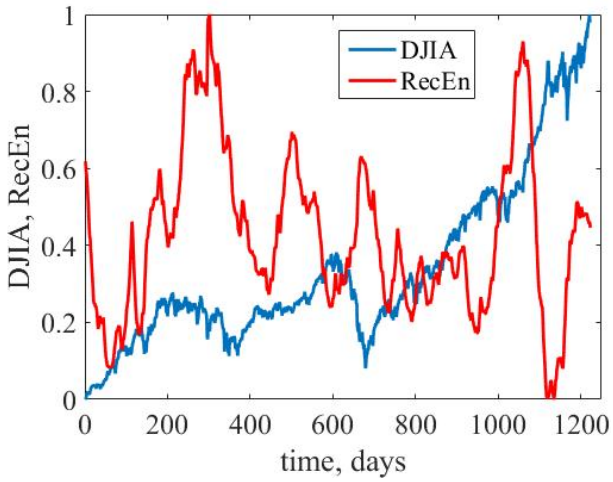
a)



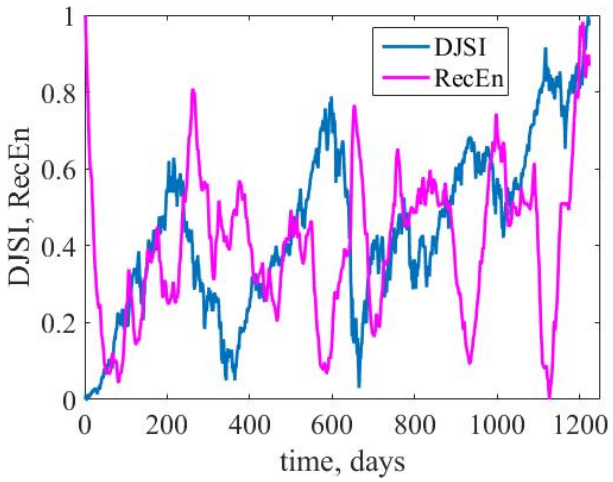
b)

Fig. 6. The recurrence probability density entropy for the time series of the DJIA (a) and DJSI (b).

Entropy recurrence time behavior for the analyzed time series is shown in Figure 7.



a)



b)

Fig. 7. The recurrence entropy for the time series of the DJIA (a) and DJSI (b).

Similarly, one can obtain the dynamics of recurrent entropies for normalized returns.

An analysis of the results indicates that the time series of the DJSI index is more complex than its classical counterpart DJIA. Moreover, the entropy indicators obtained from the analysis of the recurrence properties of the series themselves are sensitive to changes in its complexity and can serve as measures of entropy complexity.

The pattern of fluctuations of the calculated measures of complexity substantially depends on the size of the movable window. For a more detailed analysis of close-in-time noticeable fluctuations in the time series, the window size should be reduced and, on the contrary, a smoothed picture is observed with increasing window size.

These fluctuations are usually associated with critical and crisis phenomena. The fact that entropy measures respond to these phenomena can serve as the basis for constructing an indicator and precursors of crisis phenomena in stock markets [28-31].

4 Conclusions

In this paper, for the first time, entropy measures of complexity based on the analysis of recurrent properties of time series are used for a comparative analysis of sustainable development indices and their classical analogues. Three varieties of the recurrence base of entropies are considered: the entropies of diagonal lines, the recurrence probability density entropy, and recurrence entropy. Using the DJIA and DJSI indices as an example, it is shown that, firstly, all entropy measures are complexity measures and, secondly, they respond to critical and crisis conditions of the stock market.

In the future, a similar study for a set of other indices would be of interest, as well as a comparison with the results of using other quantitative measures of complexity.

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