Collection Data and Visualization Preventive Maintenance Schedule

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Abstract

The primary objective of the maintenance strategy within industrial firms is to optimize the operational uptime of production assets while minimizing downtime. Effective maintenance management is one of the key elements in achieving this goal. A Computerized Maintenance Management System (CMMS) serves as a pivotal tool in modern industrial maintenance. Based on literature overview and my own experience in mining such a system was developed and presented. This software facilitates streamlined management of maintenance operations, encompassing work orders, asset tracking, and resource allocation. And the most important thing - preventive maintenance scheduling is visualized improving possibilities of production planning

Keywords

Preventive maintenance, maintenance scheduling, CMMS, cloud platform

1. Introduction

In the realm of industrial operations, the effective management of production is a multifaceted challenge that demands a delicate balance between various elements. One crucial aspect that significantly influences the efficiency and longevity of production processes is the seamless integration of maintenance activities with production workflows. This symbiotic relationship is imperative for sustaining optimal productivity, minimizing downtime, and ensuring the longevity of equipment and machinery.

The effective management of production not only involves the meticulous planning and execution of manufacturing processes but also necessitates a proactive approach to equipment upkeep. However, for underground mining, it poses a significant challenge. Because, there are two different management structures at mine. First is the main management branch, for example head of the mining district, chief engineer, mine director. And the second - mechanical branch - district mechanic, chief mechanic. And they should have very good communication between them.

The next problem is workflow organization. For the template, we can take a typical passport of mining exploration works. It consists of the following operations [1]:

1. Bringing the hole to a safe state - 10 minutes;
2. Cleaning of the hole – 120 minutes;
3. Drilling holes – 152 minutes;
4. Drilling "plugs" (surveying slopes, hanging pipes) – 10 minutes;
5. Charging and detonating the hole – 40 minutes;
6. Ventilation of the hole – 20 minutes;
7. Fastening (combined) - 70 minutes

Summary 422 minutes. And these processes can not be parallel. It is shown on the cyclogram below.

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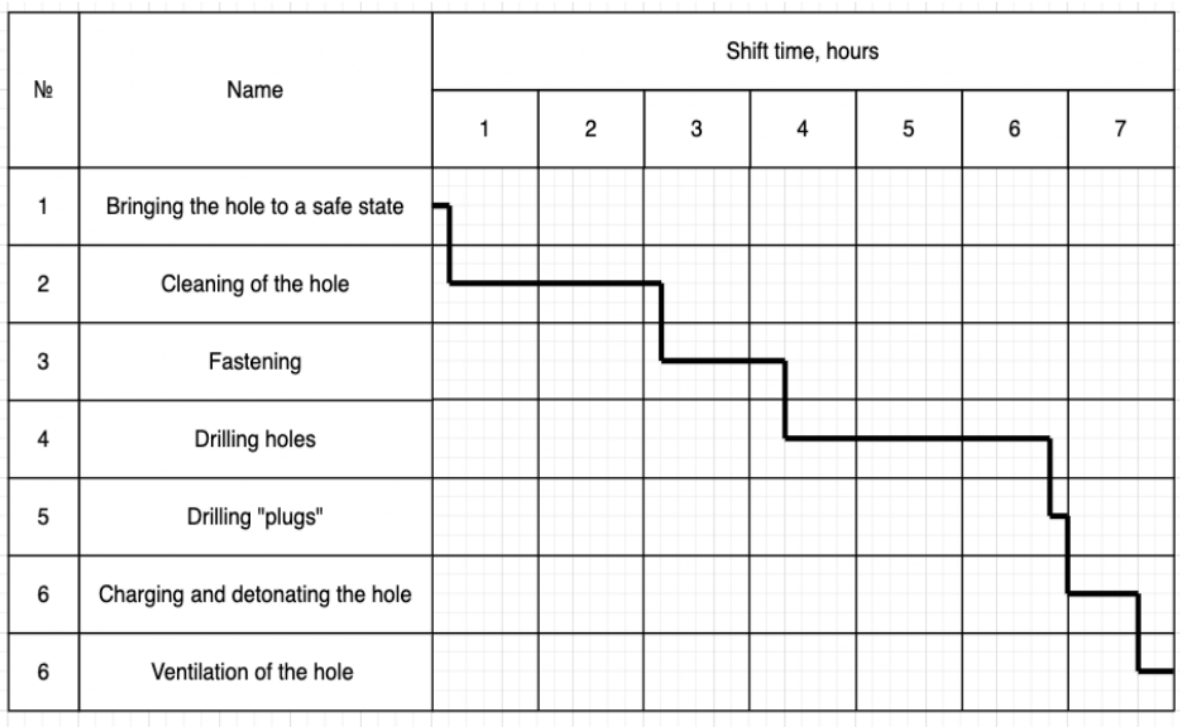

Figure 1: Cyclogram of work with a 7-hour shift

There are two mechanized operations:

1. Cleaning of the hole. For this purpose we can use underground loader Scooptram ST2D [2];
2. Drilling holes. For this purpose we can get as an example drilling rig Boomer T1[3];

Also if mining takes place in solid rocks, the hole can be fastened with anchors. In this case, the boomer also will work.

In the cyclogram above you can see, that loader will work only 2 hours per shift. But in reality, you will have 3 holes that will take place at the same time. And machine will be exploited during 6 hours per shift or 18 hours per day.

At that time, if you take a monthly plan, it will look like this:

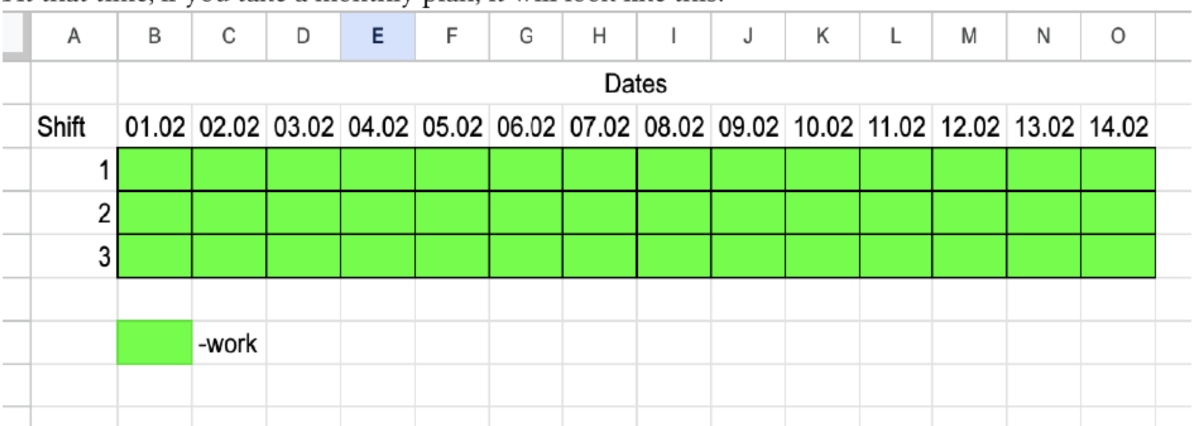

Figure 2: Example of typical working plans at mines

As you can see, usually nobody thinks about machine maintenance. However, the service manual [4] listed the procedures for each working time interval. In Epiroc Ukraine [5] based on these instructions next labor costs for preventive maintenance were developed and is presented in Table 1.

Table 1
Maintenance interval and labor costs

Maintenance interval(h)	Labor costs(man hours)
250	7
500	14
1000	21
2000	28
5000	56

As we mentioned above, these works usually are not included in the month graphic. But they are necessary. And one of the solutions for supporting combined manufacturing activity and maintenance is to create a support system with a simple graphical interface.

2. Literature overview

With the introduction of the next industrial revolution (referred to in the literature as the information age), the influence of information technologies and their application in production processes has grown significantly. Thus, companies were able to obtain a large amount of data on both production processes and maintenance processes. Many factors influenced this ability. In order to facilitate service management in production enterprises, IT systems, e.g. CMMS (Computer Maintenance Management System), were developed [6].

Investigation [7] shows that basically CMMS should have the following sections:

1. Preventive Maintenance Management: that supports the planning, scheduling and control of activities.
2. Work Orders Management: that allows setting and releasing of work orders to the maintenance technicians.
3. Inventory control: giving access to spare parts availability.
4. Assets Management: that consists of recording all assets (or equipment) and a historical record of repairs and equipment parts list.
5. Report Management: CMMS processes large amounts of data and produces performance indicators.

Rakesh Sharma and N. Govindaraju highlight that, based on the complexity of the chosen system, the general functions of a CMMS can be as follows [8]:

1. Historical tracking of all work orders generated which become sortable by equipment, date, person responding, etc.;
2. Work order generation, prioritization, and tracking by equipment/component;
3. Tracking of scheduled and unscheduled maintenance activities;
4. Storing of all technical documentation or procedures by component;
5. Storing of maintenance procedures as well as all warranty information by component;
6. Real-time reports of ongoing work activity.
7. Calendar- or run-time-based (Gantt chart) preventive maintenance work order generator.
8. Complete parts and materials inventory control.
9. Capital and labor cost tracking by component as well as shortest, median, and longest times to close a work order by component.
10. PDA interface to streamline input and work order generation.
11. Outside service call/dispatch capabilities.

In [9] pointed out that CMMS should store information about equipment, maintenance data and schedules, failure history, and parts inventory [9]. Smarter maintenance systems need to meet certain requirements [10]:

1. Support maintenance strategy selection;
2. Improve utilization of machines;
3. Accelerate maintenance planning;
4. Increase planning quality;
5. Improve usability;

6. Flexibility of IT systems;
7. Structure functions modularly for quick scenario adaption.

Analyzing these lists, we can conclude that they coincide and require the same elements. However, some organizations and researchers go beyond these fundamentals by supplementing their CMMS with additional benefits and features. And one of the most interesting is a tool for scheduling graphic.

In [11] proposed design for scheduling algorithm. The tasks ordering is divided into two steps. First, all the maintenance tasks are sorted by a criticality index for equipment, designated by Business Impact Rating (BIR), in descending order. Then, for each maintenance task with the same BIR, next sorting is done by deadlines. The tasks will be assigned following this last order. Both orderings have the aim to minimize delays in the execution of maintenance tasks, especially in the most critical equipment. Maintenance tasks with the same BIR and due date will be located by their processing times in descending order. Apart from serving as a means to prioritize task assignments, these sorting methods also facilitate the visual representation of upcoming maintenance tasks within a short-term timeframe. Furthermore, they play a supportive role in negotiations between manufacturing and maintenance departments, helping allocate time for the execution of preventive maintenance activities. The visualization is possible a table in the company's CMMS that contains all tasks ordered to be scheduled [11].

The main goal is the creation of an integrated schedule that minimizes the machine's unavailability and the weighted sum of total costs [12]. That is why in [12] the author uses additional financial parameters for creation of scheduling:

1. Total number of jobs
2. The processing time of the job
3. The arrival time of the job
4. The type of mold required by the job
5. The due time of the job
6. The penalty cost per unit time of delay of the job
7. The holding cost per unit time of the job
8. The mold set
9. The duration of a mold replacement activity
10. Duration of a preventive maintenance action
11. The cost of a preventive maintenance action

In the list above there are two outstanding points. First, the author narrowed down the problem to using a mold set. And the second, more important thing - the cost of carrying out the work is taken into account.

3. Development system

Based on the previous point our system will have key features of a CMMS and pay attention to the financial aspect of preventive maintenance. At early stages it will give the understanding of the cost for such works. When the system is used in production environment, users will make errors. They can be divided into the following types:

1. Skipping regular service
2. Shift in time for maintenance
3. Installation of non-original or even low-quality spare parts

In summary, these can lead to breaking down the equipment, machine or some part of them. As a result, operators will incur additional production costs. Collecting this data we can compare usual cost and usual cost + cost overrun by unplanned repairs. Visualization difference can be used for changing views on preventive maintenance organization.

3.1. Assets Management

One of the core system data. It consists of two parts:

3.1.1. List of machines

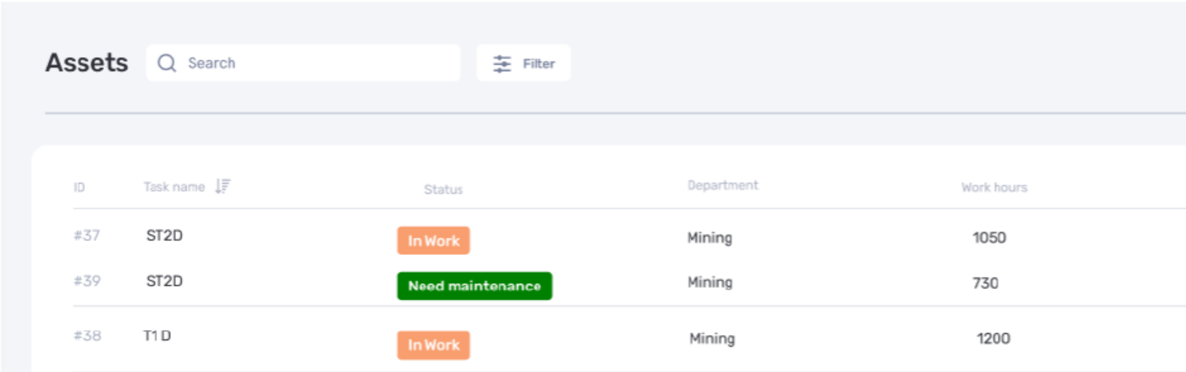

Figure 3: Enumeration of assets

Besides main info has operating hours and status. By default can be

1. Working
2. Inactive
3. Broken,
4. Hold
5. Need maintenance
6. Repair

And also we suggest custom fields for different parameters of the machine with saving history. For example, for ST2D it can be hydraulic oil level, transmission oil level, battery charge at the start of the shift (it's essential for successful beginnings of the shift in underground mining conditions).

Collection of such data in future versions may establish a relationship between states and theoretical failures.

3.1.2. Spare parts catalog

Divided into two areas. First is documentation storage. For now, it has no integrations. That is why all data should be created manually. But users can upload docs manually as a file in any format.

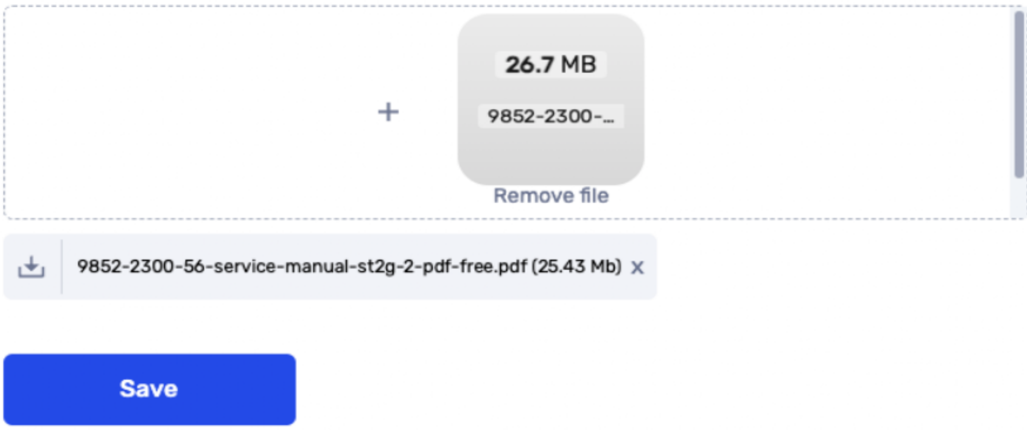

Figure 4: Part of the interface for creating and editing files

3.2. Assets Management

At first we need a list of technicians, who will do maintenance.

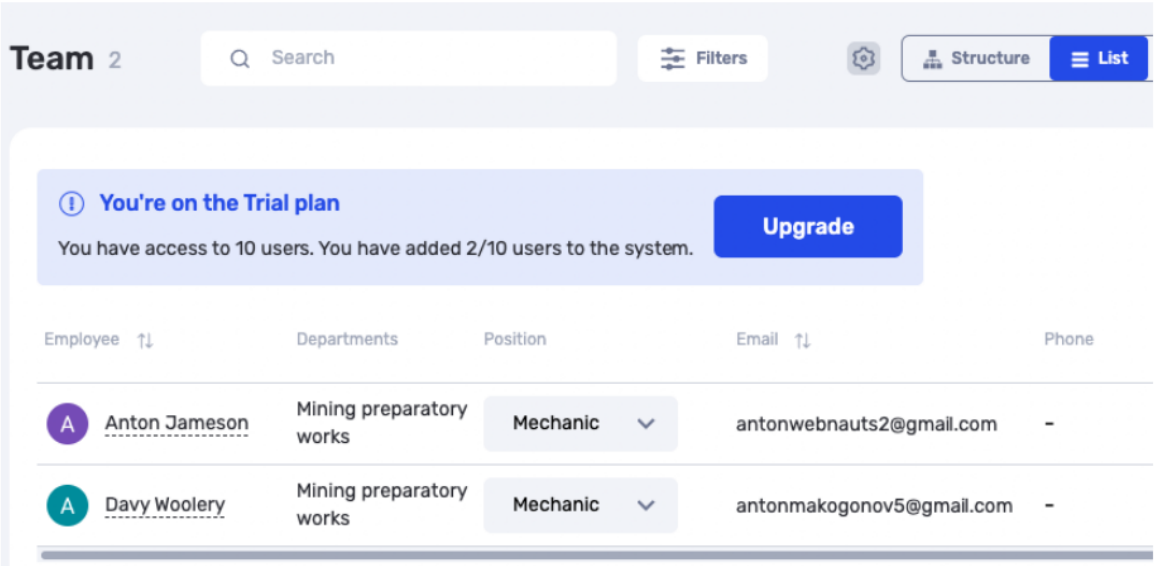

Figure 5: Company participant list

Contains the main info about position, department and contacts. Also for future calculation of preventive maintenance action, every employee has their own rate $/per hour and history of rate changes.

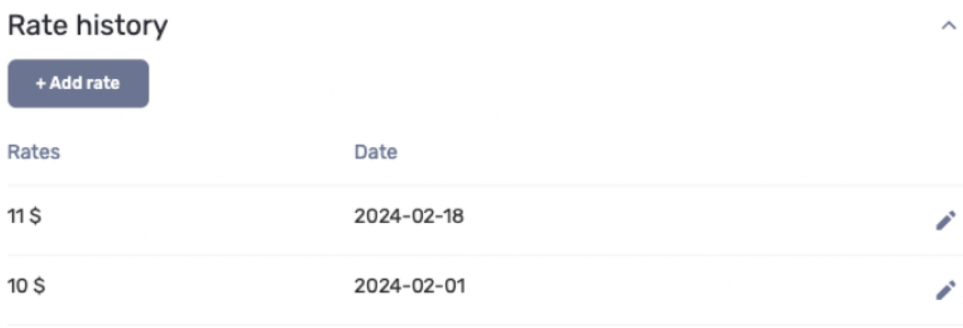

Figure 6: Employee rate history

And the main part of order management is the task system. Tasks can be united into projects and split into subtasks, contain all necessary information for future scheduling graph and cost planning:

1. Project
2. Name
3. Status
4. Manager (head)
5. Responsible
6. Planned start and finish
7. Planned time for executing
8. Priority
9. Additional description
10. Necessary documents (instructions)
11. List of spare parts

3.3. Preventive Maintenance Management

The main element of this section was described in the previous point. Managers can create, change, delete and view tasks according to their permissions in the system. But in the form of the list it is not very informative. The best way to display this is a Gantt chart.

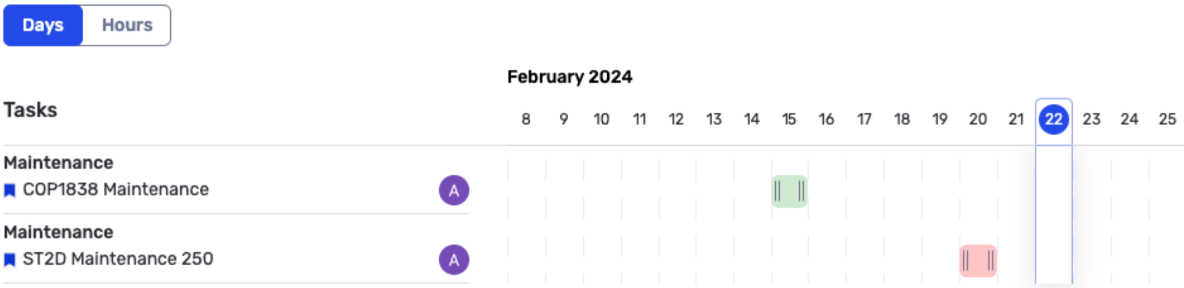

Figure 7: Gantt chart by days

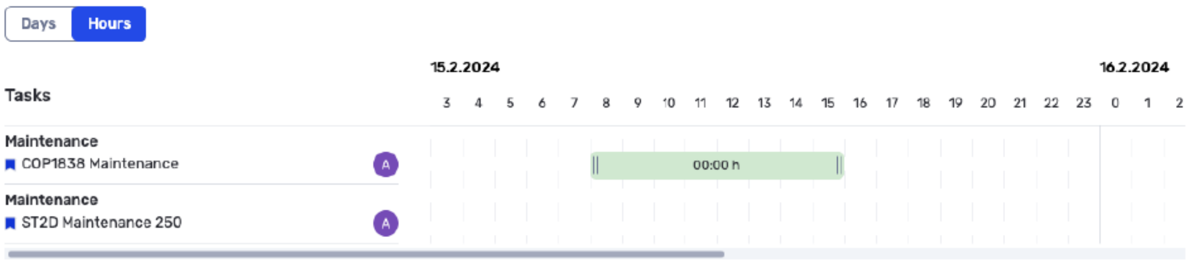

Figure 8: Gantt chart by hours

It has two modes: daily and hours. Colors have the following logic:

1. Green - task was successfully completed
2. Red - it was not done in at the appointed time
3. Orange - the task must be completed the next day or on the same day deadline
4. Blue - future works

Such a display greatly facilitates control over the execution of tasks. The next element for management is the employee working calendar.

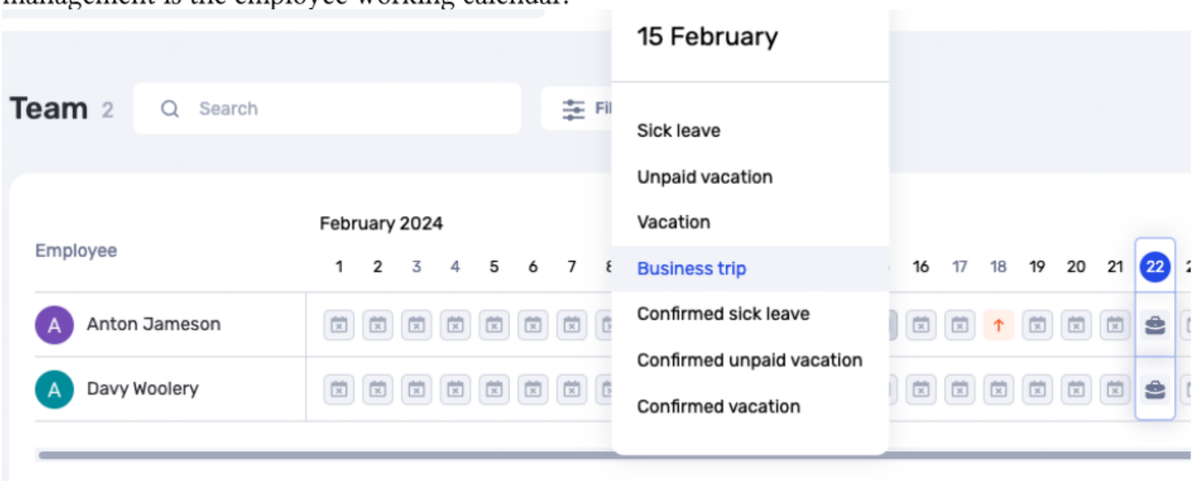

Figure 9: Employee calendar

With its help, the management can efficiently plan various aspects such as vacation time, sick leave, business trips, or any other types of travel. By seamlessly integrating the data presented in the Gantt chart with the information available on this screen, we gain a comprehensive overview, enabling us to manage human resources more effectively.

The synchronized data not only facilitates accurate scheduling but also assists in identifying patterns and trends related to employee availability. This holistic approach to human resource management enhances decision-making processes, allowing for optimized workforce planning and resource allocation.

Moreover, the integrated platform fosters better communication within the organization, as team members and management alike can stay well-informed about the availability and planned absences of colleagues. This transparency contributes to a more collaborative and efficient work environment.

3.4 Inventory control

Generic framework/model that can be easily adopted and customized by the stakeholders in any industry requires assets maintenance [13]. For quality planning, mechanics need to know how many parts they have in stock. Therefore, we suggest keeping records of their quantity and applications for their supply in CMMS. It will be connected with tasks. Every non finished job blocks the necessary number. After finishing - write off from the warehouse. That`s why users will have historical records of movement of materials.

Furthermore, as part of its proactive functionality, the system incorporates an alert mechanism. Based on data about machine working hours system can predict the next maintenance date and type. For every interval managers should have not only a list of operations, but also a spare parts list.

In cases where the spare parts required for upcoming maintenance are insufficient or fall below the specified threshold, the system generates timely warnings. This proactive warning system adds an extra layer of foresight to the maintenance planning process, preventing potential disruptions due to a lack of necessary components. Managers can then promptly address the shortage, ensuring that the maintenance activities proceed seamlessly without unexpected delays.

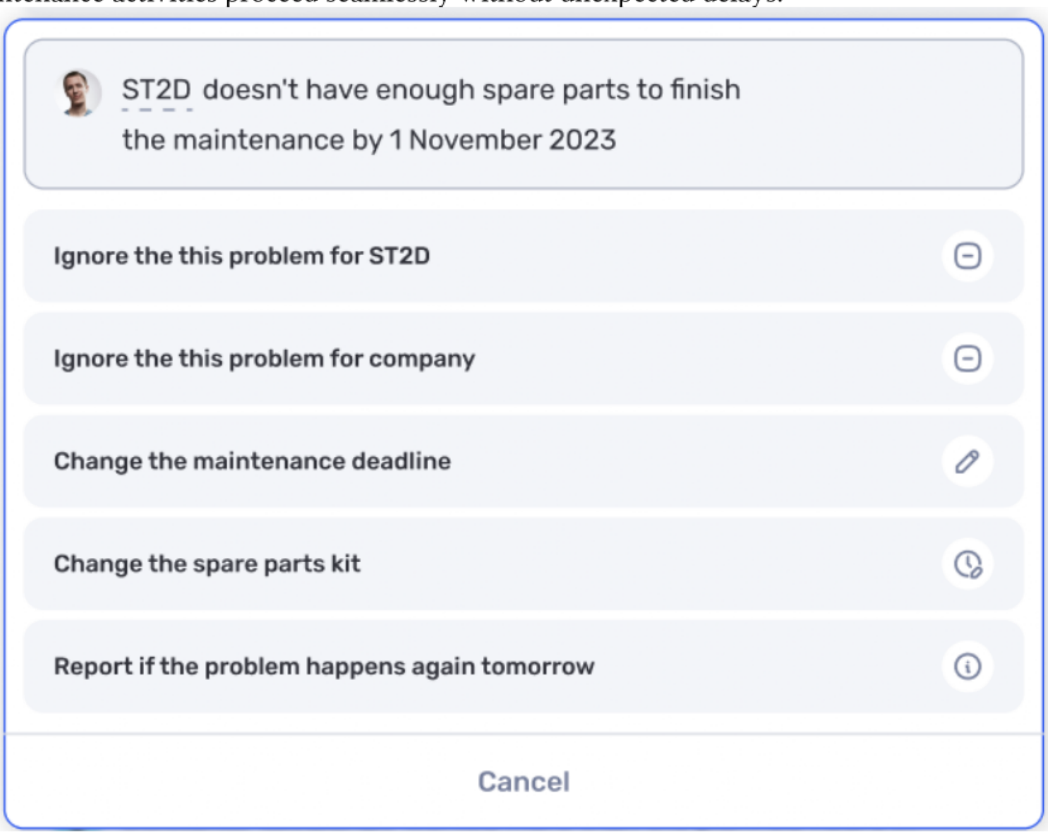

Figure 10: Alert notification in the system

But it is not only notification. It is a new thing that needs action from the reviewer. Manager who leads the team should make a plan of what to do in every situation connected with the absence of spare parts or human resources.

In essence, the system not only predicts maintenance needs based on machine working hours but also acts as a vigilant assistant by providing timely notifications. This integrated approach empowers managers to maintain a well-prepared and efficiently functioning production environment.

3.5 Report Management

As the system has rates such report will be very useful not only for inner mining departments, but also for service companies like Epiroc or Sandvick. Often they have contracts with organizations for maintenance works. In this case engineers visit industrial objects and every hour will be paid (field billable). Field Salary represents multiplying technician hours and his rate.The difference between these fields is revenue.

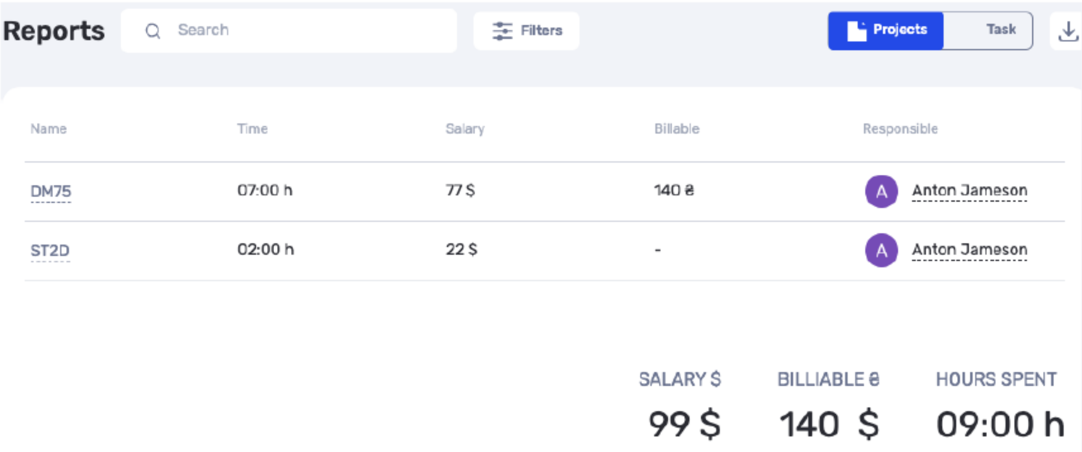

Figure 11: Reports

Other opportunities for controlling and reporting are:

1. Kanban - helps to evaluate state of tasks
2. Gantt chart
3. Employee calendar - shows hours for every participant and marks incomplete works or overtimes (actual for time to material scheme).
4. Excel export

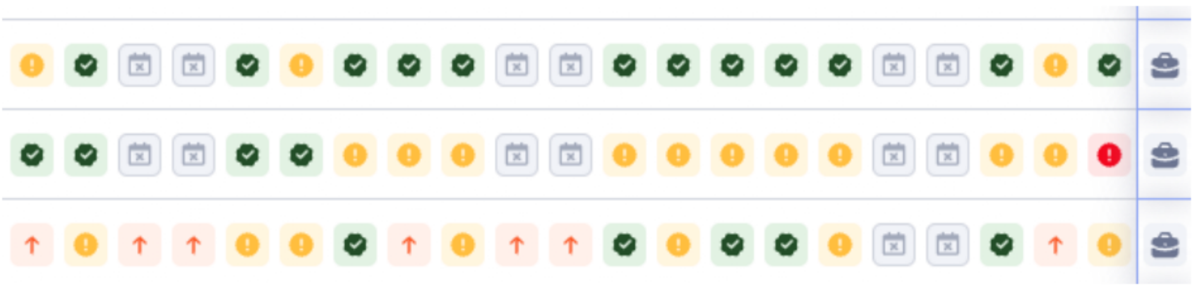

Figure 12: Visualized employee hours (green - normal, yellow - incomplete, rose - overtime, red - not work, gray - holiday)

4. Applying system

For example, we take maintenance for ST2D loader. Conditions taken from the first section. Start from the 1st of the month. Machine works 18 hours during a day. First PM (preventive maintenance) action can take place in 250(nearest interval)/18 = 14 days. Accordingly, we will have two PMs in the first month. It should be divided into tasks and can be shown on the Gantt chart. And they colorized depending on status and the deadline.

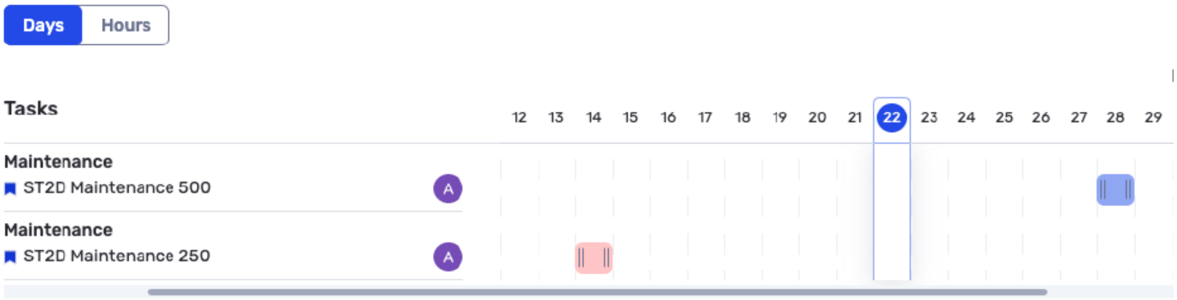

Figure 13: Planned maintenance

Visualization of this data can help to adjust the production schedule for a month, because the machine will not be able to do the work for two shifts.

5. Discussions

Comparing previous investigations in literature overview and developed system we can come to the conclusion that the main requirements were realized.. Much attention was also paid to the financial part of maintenance. Similar work was presented in [14]. Computer based maintenance system (CBMS) was developed for The Metro Rail Transit (one of two rail transits in the Philippines) [14]. It consists of nine modules:

1. Dashboard;
2. Administration;
3. Ticket request;
4. Scheduling;
5. Spare parts monitoring;
6. Service;
7. User administration;
8. Train monitoring;
9. Report generation.

As the system was specialed for railway industry, it has non-common sections - tickets, dashboard, administration and train monitoring. This is also true for [15], where an aircraft maintenance system was developed. In addition to the specified elements, optimized maintenance schedules take into account hangar and parking spot capacity [15], which is not important for mining.

Scheduling problems aim to allocate a set of limited or unlimited resources to a set of activities over a predefined planning horizon. Multi-skilling occurs when the resources are limited and have several capabilities called 'skills' in processing different tasks. As a general classification of the constraints in multi-skilling, we categorize them as task-based constraints, skill based constraints and resource-based constraints [16]. The represented employee section is not very deep. Because it ignores skills availability (other two constraints are present). Of course, in the real world, a manager can not appoint a task for a human, who can not perform it. But usually preventive maintenance actions are simple, and only trainees can not execute them. At the same time, multi-skilling as a business strategy has gained remarkable attention because of its many benefits to employees (job security, greater job opportunities, better growth prospects, etc.) and organizations (optimal resource schedule, increased productivity, flexible workforce, etc.) [16].

In [17], authors consider three limitations: total maintenance cost, maintenance time and the ability of maintenance personnel. The second and third constraints are applicable to our system. However, the first constraint is somewhat contentious. In the context of mining machinery operating in aggressive environments, replacing spare parts is important. We cannot refuse it. With the implementation of the asset hierarchy, it is possible to control the costs produced by every equipment, in order to study the origin of these results [18] - such a graphical interface was not released. But it is very useful for analyzing equipment with higher maintenance costs and, as a result, making designs about future steps. The machine may be overhauled or written off, and the fleet will need to be updated accordingly.

In [8] new integration form between AR and CMMS allows the enhancement of awareness against unexpected breakdown, and hence, provides right actions to deal with it through explicit visualization of asset information, service manual, diagnostic procedure and availability of the spare parts. The continuous improvement of augmented reality technologies coming to the market makes the implementation of augmented reality more feasible to solve real-world industrial problems, especially for service. Tasks performed during maintenance often consist of complicated instructions and a large volume of information such as recognition of the right component and precise procedures for dismounting and mounting. To ensure smooth and efficient maintenance, it is critical to provide AR information in the user's field of view, leaving the user's hands free to perform a controlled task. This approach enables the efficient planning and presentation of maintenance processes to unskilled operators. It guides them in diagnosing issues and intuitively and safely performing the appropriate maintenance tasks [8]. But we think that this does not apply to mining. Because AR equipment is expensive and needs to be used in a non-aggressive environment. In mine, it gets dirty quickly and moisture destroys it very quickly. The best for documentation in such conditions is a mobile phone and a mobile application

6. Conclusions

In the article, a computer system for organizing preventive maintenance schedule was developed and demonstrated. Broad requirements for visualization and functionality were released. Also, data collected in this system (maintenance cost, information about previous inspections, e.g., time since last maintenance or type of maintenance intervention, maintenance reports and work orders, availability and reliability of the components [19]) can be used for optimization.

Current system can be useful not only for mining, but also for other industries. For example, most airlines now use a manual approach to scheduling heavy maintenance inspections. This manual process depends on the expertise of maintenance planners, leading to frequent adjustments in the maintenance schedules due to uncertainties. [20]. Data in CMMS can decrease the workload and minimize the need for frequent revisions of extensive maintenance schedules, taking into account uncertainties related to heavy maintenance check duration and daily aircraft utilization. [20].

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