UDC 621.394.74:519.872

Vagif Gasimov
Doctor of Technical Sciences, Professor,
Head of the Department of Computer Technologies, Azerbaijan Technical University, Baku, Azerbaijan
ORCID ID 0000-0003-3192-4225
vaqif.qasimov@aztu.edu.az

Balami Ismailov
Doctor of Technical Sciences,
Professor of the Department of Computer Systems and Programming of the National Aviation Academy, Baku, Azerbaijan
ORCID ID 0009-0002-3013-9161
balemi@rambler.ru

ANALYSIS OF THE RESULTS OF SIMULATIVE MODELLING OF THE INFORMATION SECURITY SYSTEM IN THE CORPORATE NETWORKS OF HIGHER EDUCATION INSTITUTIONS

Abstract. The analysis shows that the insufficient level of information security in service networks is the main cause of huge losses for enterprises. Despite the appearance of a number of works to solve this problem, there is currently no unified system for assessing information security. This shows that this problem has not yet been sufficiently studied and relevant. This work is one of the steps towards creating a system for assessing information security in service networks.

The purpose of the work is to develop an algorithm and simulation model, analyze the results of the simulation model to determine the main characteristics of the information security system (ISS), providing the ability to completely close all possible channels of threats by controlling all unauthorized access (UA) requests through the protection mechanism (PM).

To solve the problem, a simulation method was applied using the principles of queuing systems (QS). This method makes it possible to obtain the main characteristics of the ISS from the UA with an unlimited amount of buffer memory (BM). Models, an algorithm and a methodology for the development of ISS from UA are proposed, which is considered as a single-phase multi-channel QS with an unlimited volume of BM. The process of obtaining simulation results was implemented in the GPSS World modeling system and comparative analyzes of the main characteristics of the ISS were carried out for various laws of distribution of output parameters. At the same time, UA requests were the simplest flows, and the service time was subject to exponential, constant and Erlang distribution laws.

Conducted experiments based on the proposed models and algorithm for analyzing the characteristics of the ISS from the UA as a single-phase multi-channel QS with unlimited waiting time for requests in the queue confirmed the expected results. The results obtained can be used to build new or modify existing ISS in corporate networks for servicing objects for various purposes. This work is one of the approaches to generalizing the problems under consideration for systems with an unlimited volume of BM. Prospects for further research include research and development of the principles of hardware and software implementation of ISS in service networks.

Keywords: unauthorized access (UA); information security systems (ISS); information security; queuing systems (QS); protection mechanism (PM); simulation modeling.

1. INTRODUCTION

Formulation of the problem. The work is devoted to the study of information security problems in service networks with an unlimited volume of BM. An analysis of research and experience in this area shows that insufficient security of information resources in corporate service networks leads to huge losses in enterprises, including higher educational institutions, which emphasizes the high importance of the problem of information security [1], [2].

Analysis of the current state of the problem in the field of information security, incl. development of ISS, shows that there are serious difficulties associated largely with the lack of a unified system for assessing information security that allows for a quantitative assessment in the design and operation of ISS for service networks [1], [3], [4]. It should be noted that at present, due to insufficient experience in designing an ISS, the tasks of its construction must be solved in the early stages of designing a service network.

Based on the above, we can say that the problem of information security in service networks has not been sufficiently studied and is relevant [1], [5] [6]. It should be noted that one of the most obvious causes of information security violations is the deliberate request of UA to confidential information by illegal users and subsequent unwanted manipulations with this information [1], [7]. The effectiveness of ensuring information security in service networks is mainly determined by the level of security of the service network itself [8], [9], [10], and therefore the implemented protection mechanisms are determined.

Due to the existence of the fact that the protection system does not completely close all possible channels of manifestation of threats in the structure, a new ISS structure was proposed in [1.p.47], where, unlike the existing structure, each input flow is provided with a PM for servicing.

The work [1] proposes a lossy ISS structure with limited and unlimited volume of BM, ensuring maximum information security of service networks by ensuring control of the transition of all UA requests through the PM. Here we analyze the results of an ISS simulation model with an unlimited volume of BM for wide values of input and output parameters.

Note that when solving the security problem in service networks, the main factor is the network security class, which is determined by a set of PMs implemented in the form of hardware or software in the network [1], [11],[12]. As already noted, in service networks, along with normal requests, there are UA requests for confidential information from illegal users, which can lead to disruption of the network.

It should be noted that the PM, influencing the entire process of ensuring information security, can function in constant information interaction with other elements of the ISS. It is known that the functioning of the PM is described by such possible states as serviceable, faulty, diagnosed, restored [13], [14]. In ISS, risk is considered the possibility of the occurrence of some unfavorable event associated with the characteristics of the unreliability of the PM, entailing various types of losses [1], [15],[16]. However, approaches associated with risk arising from the reliability characteristics of the PM are not considered in this work, i.e. it is assumed that all MP are reliable. At the same time, **the object of research** is considered to be a ISS from the UA with an unlimited amount of buffer memory in service networks. **The subject of the study** is to determine the main characteristics of the ISS from the UA data with an unlimited amount of buffer memory in service networks. **The purpose of the work** is to develop an algorithm and a simulation model, as well as to analyze the results of the simulation model to determine the main characteristics of an ISS with an unlimited volume of BM.

2. THEORETICAL BASIS

We consider the structure of the ISS with an unlimited calculation of the BM (Fig. 1), in which all input flows receive a PM for servicing. It is assumed that the considered structure of the ISS ensures information security of network maintenance. This structure is a hardware and software complex that interacts with streams of random events that determine the actions of attackers, incorrect distribution of access rights, the use of unauthorized software, as well as errors in software and hardware systems for identification and authentication.

It is assumed that an intruder (attacker, UA requests) at the system input creates various threats with an intensity λ of . ISS consists of N - the number of PMs that carry out service delays $\tau_0 = \frac{1}{\mu}$, where μ - the intensity of request servicing. If we consider the intruder's block as a source of information, and the PM as parallel operating devices, then as a mathematical model of the ISS we can consider a single-phase, multi-channel QS with an unlimited volume of BM. At the same time, the complexity of servicing UA requests is characterized by screening out UA requests, detecting and classifying UA attempts, blocking or passing UA requests to protected resources, etc.

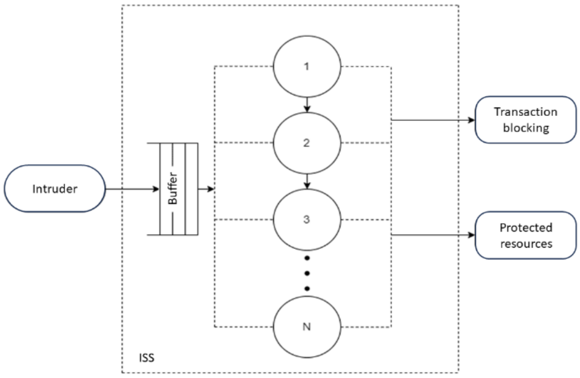


Fig. 1 Structure of ISS with unlimited volume of BM

Taking into account the noted complex nature of servicing UA requests, as a function of the probability of loss of UA requests from failure due to overload of the servicing system for a system with unlimited waiting (that is, for a system with unlimited BM), in [1p.49] it is proposed to use the Erlang delay function:

$$p_1(N,\lambda,\mu) = \frac{\rho^N / [(N-1)!\,(N-\rho)]}{\sum_{k=0}^{N-1} \rho^k / k! + \rho^N / [(N-1)!\,(N-\rho)]}$$

Then the problem of determining the optimal values of the ISS characteristics can be formulated as minimizing the mathematical expectation of the function of the probability of loss of requests UA from refusal due to overload of the service system:

$$M\left[\frac{\rho^N / [(N-1)!\,(N-\rho)]}{\sum_{k=0}^{N-1} \rho^k / k! + \rho^N / [(N-1)!\,(N-\rho)]}\right] \to \min$$

$$\text{at } \lambda \ge \lambda_0, \mu \ge \mu_0, N \ge N_0$$

$$L_q \le L^0$$

where M - is the sign of the mathematical expectation; $\rho = \frac{\lambda}{\mu}$ - reduced intensity; λ_0, μ_0, N, L^0 - permissible limit values λ, μ, N, L_q; L_q - average value of the queue length, i.e. a value that determines the volume of BM.

Problems associated with insufficient information security in service networks and the task of determining the optimal values of the characteristics of the ISS from the UA for various cases are considered and analytically solved in [1] and the optimal values of the characteristics of the QS with and without waiting for requests in the queue are obtained. However, for a detailed analysis of the characteristics of the ISS from the UA for wide values of input and output parameters, it is preferable to use simulation modeling methods, considering it as a single-phase, multi-channel QS with and without waiting.

Considering the volume of the obtained results of the simulation model, here we will limit ourselves to considering the analysis of the results of the QS simulation model with unlimited waiting for requests in the queue, covering wide values of input and output parameters.

Thus, based on the presented structure of the ISS, the work sets the task of analyzing the results of simulation of a single-phase multi-channel QS with an unlimited volume of BM. To do this, using the simulation method, it is necessary to determine the structural and temporal characteristics of the ISS within the given average values λ, μ and the number of parallel operating service devices (PM).

3. RESEARCH METHODS

To determine the characteristics of the ISS that allow it to function within limited resources, it is assumed that the input flow of information, i.e. UA requests are the simplest, and the service time is subject to exponential, constant and Erlang distribution laws. To adequately describe the functioning of the ISS from the UA, algorithms for a simulation model of the service process have been developed for three cases.

- The receipt of requests to the ISS and the service time are subject to the exponential distribution law.

- The receipt of requests in the ISS is subject to an exponential distribution law, and the service time is subject to a uniform distribution law.

- The receipt of requests in the ISS is subject to the exponential distribution law, and the service time is subject to the Erlang distribution law.

The developed algorithm for the functioning of the ISS from the UA includes the following steps.

1. The average values λ, μ and minimum permissible limit values of the number of parallel operating service devices (PM) are set. For the purpose of a detailed analysis of the properties of the system under study, a table structure is organized for the waiting time in the queue and the time spent by requests in the system. In this case, the upper limit of the first frequency interval, the value of all other frequency intervals and the number of frequency intervals are set. The goal here is to construct density histograms of the distribution of waiting time in the queue and the time spent by requests in the system based on the accumulation of the frequency of a random variable falling into given frequency intervals.
2. When an UA request is received in the ISS, at least one free PM is searched; if there is one, the UA request is sent to this free PM and the UA requests are filtered out, and attempts of UA are detected and classified. As a result, the original UA flow is rarefied with $p_1, p_2 = 1 - p_1$ certain probabilities, forming an output flow, i.e. blocking is likely to occur p_1 or UA requests to protected resources are likely to be passed $p_2 = 1 - p_1$.
3. If all PMs are busy, the UA request waits in a queue in the system's BM until one of the PMs is released, since there is always free space in the BM.
4. After one of the PMs is released, the UA request arrives at this free PM and the servicing process occurs in accordance with the third step of the algorithm.
5. Note that the probability values $p_1, p_2 = 1 - p_1$ are determined based on statistical analysis.

Based on the proposed algorithm, covering three cases of operation of the ISS from the UA as a single-phase, multi-channel QS with an unlimited capacity of BM, models for simulating the ISS from the UA with an unlimited amount of buffer memory have been developed in the GPSS World modeling language. During the simulation, the model allows you to determine $N = \overline{2,5}$:

- number of requests to the PM (ENTRIES);
- average queue length (AVE.C);
- PM utilization rate (UTIL);
- mean value of the corresponding random variable (MEAN);
- standard deviation of a random variable (STD.DEV);
- lower and upper limits of the frequency interval (RANGE);
- the number of queries waiting for a specific condition to be fulfilled, depending on the state of this table (RETRY);
- the number of random values falling into a given interval (FREQUENCY);
- accumulated frequency, expressed as a percentage of the total number of random values (CUM.%).

4. RESULTS AND DISCUSSION

Based on the execution of the simulation model for $N = \overline{2,5}$ average values of real data, with $\lambda = 1/3500$ ms and $\mu = 1/1700$ ms results were obtained for three cases:

1. Receipt of requests to the ISS and service time are subject to an exponential distribution law.

In the first case, the results of a simulation model of the functioning of the ISS were obtained - reports (fragments of reports are shown in Fig. 2, on the basis of which Table 1 was created), and histograms of the distribution densities of the residence time T_U and waiting time T_W of requests, at $N = \overline{2,5}$ (Fig. 3).

```
QUEUE            MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1           3204 3204 103205     37  1521.830      0.435      0.435   0

STORAGE          CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL              2    0    0    2   100002   1    1.999  1.000    0 3203

TABLE            MEAN    STD.DEV.       RANGE           RETRY FREQUENCY CUM.%
 T_W             0.434    0.291                           0
                                    _  -       0.000                69    0.07
                                0.000  -       0.001                20    0.09
                                0.001  -       0.001                22    0.11
                                0.001  -       0.002                23    0.13
                                0.002  -       0.002                46    0.18
                                0.002  -       0.002                60    0.24
                                0.002  -       0.003                43    0.28
                                0.003  -       0.003                61    0.34
                                0.003  -       0.004                45    0.39
                                0.004  -  _                      99612  100.00
 T_U             0.435    0.291                           0
                                    _  -       0.001                52    0.06
                                0.001  -       0.002                36    0.10
                                0.002  -       0.002                61    0.17
                                0.002  -       0.003                83    0.26
                                0.003  -       0.004                94    0.36
                                0.004  -       0.005                83    0.45
                                0.005  -       0.006                75    0.54
                                0.006  -       0.006                66    0.61
                                0.006  -       0.007                86    0.71
                                0.007  -  _                      89305  100.00
```

```
QUEUE            MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1             23    2 100004  52060     1.060      0.000      0.001   0

STORAGE          CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL              3    0    0    3   100003   1    2.068  0.689    0    1

TABLE            MEAN    STD.DEV.       RANGE           RETRY FREQUENCY CUM.%
 T_W             0.000    0.001                           0
                                    _  -       0.000             74405   74.40
                                0.000  -       0.001             12221   86.62
                                0.001  -       0.001              6352   92.98
                                0.001  -       0.002              3205   96.18
                                0.002  -       0.002              1772   97.95
                                0.002  -       0.002               982   98.94
                                0.002  -       0.003               506   99.44
                                0.003  -       0.003               263   99.70
                                0.003  -       0.004               113   99.82
                                0.004  -  _                        183  100.00
 T_U             0.001    0.001                           0
                                    _  -       0.001             50961   56.59
                                0.001  -       0.002             24672   83.98
                                0.002  -       0.002              9407   94.43
                                0.002  -       0.003              3418   98.22
                                0.003  -       0.004              1056   99.39
                                0.004  -       0.005               381   99.82
                                0.005  -       0.006               119   99.95
                                0.006  -       0.006                35   99.99
                                0.006  -       0.007                 8  100.00
                                0.007  -                             2  100.00
```

```
QUEUE            MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1             13    0 100002  81325     0.202      0.000      0.000   0

STORAGE          CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL              4    2    0    4   100002   1    2.052  0.513    0    0

TABLE            MEAN    STD.DEV.       RANGE           RETRY FREQUENCY CUM.%
 T_W             0.000    0.000                           0
                                    _  -       0.000             94911   94.91
                                0.000  -       0.001              3559   98.47
                                0.001  -       0.001              1121   99.59
                                0.001  -       0.002               304   99.89
                                0.002  -       0.002                84   99.98
                                0.002  -       0.002                21  100.00
                                0.002  -       0.003                 1  100.00
                                0.003  -       0.003                 1  100.00
 T_U             0.001    0.001                           0
                                    _  -       0.001             63356   70.38
                                0.001  -       0.002             19522   92.07
                                0.002  -       0.002              5293   97.95
                                0.002  -       0.003              1350   99.45
                                0.003  -       0.004               360   99.85
                                0.004  -       0.005               106   99.97
                                0.005  -       0.006                28  100.00
                                0.006  -       0.006                 1  100.00
                                0.006  -       0.007                 1  100.00
```

```
QUEUE            MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1              9    0 100002  93071     0.051      0.000      0.000   0

STORAGE          CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL              5    3    0    5   100002   1    2.070  0.414    0    0

TABLE            MEAN    STD.DEV.       RANGE           RETRY FREQUENCY CUM.%
 T_W             0.000    0.000                           0
                                    _  -       0.000             99001   99.00
                                0.000  -       0.001               817   99.82
                                0.001  -       0.001               167   99.98
                                0.001  -       0.002                15  100.00
                                0.002  -       0.002                 2  100.00
 T_U             0.001    0.001                           0
                                    _  -       0.001             66085   73.36
                                0.001  -       0.002             17898   93.22
                                0.002  -       0.002              4488   98.20
                                0.002  -       0.003              1185   99.52
                                0.003  -       0.004               318   99.87
                                0.004  -       0.005                94   99.98
                                0.005  -       0.006                20  100.00
                                0.006  -       0.006                 1  100.00
```

Fig.2. Fragments of reports for the first case, when $N=\overline{2,5}$

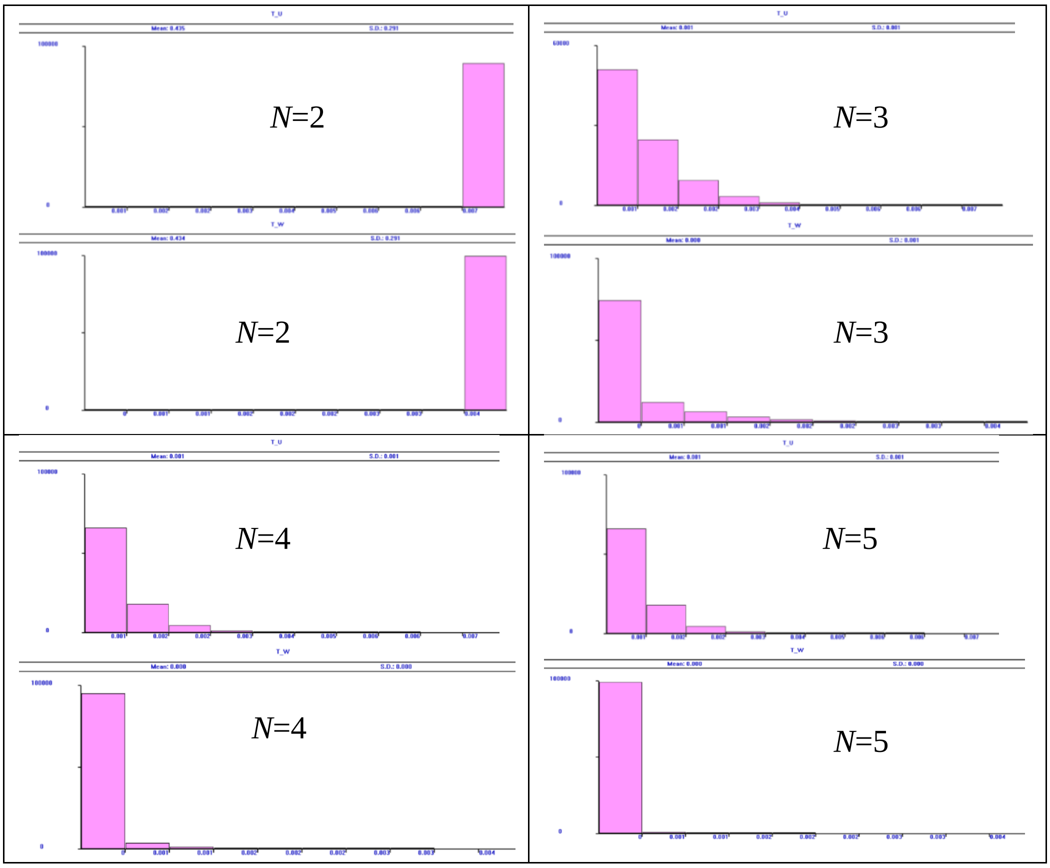


Fig.3. Histograms of the distribution densities of the residence time T_U *and waiting time* T_W *of requests for the first case, for* $N=\overline{2,5}$.

Table1 provides the dynamics of changes in system characteristics, i.e. the number of requests in the PM, the average queue length and the PM utilization rate depending on the number of PM (N) during the simulation for the first case.

Analysis of the dynamics of changes in these characteristics shows that with an increase in the number of PMs from 2 to 5:

– the number of requests in the PM remains almost unchanged, i.e. the difference is 1;
– the average queue length increases, and the difference is 0.071;
– the coefficient of utilization of the PM decreases, and the difference is 0.586.

Table 1

Dynamics of changes in system characteristics depending on the number of PMs for the first case

Number of PM	Number of requests to the PM (ENTRIES)	Average queue length (AVE.C)	PM utilization rate (UTIL)
2	100002	1.999	1.000
3	100003	2.068	0.689
4	100002	2.052	0.513
5	100002	2.070	0.414

In the models, for the purpose of constructing histograms, 10 frequency intervals were selected, and as the length of the frequency intervals, T_W 0.0004 time units were selected for the waiting time of requests in the queue, and T_U 0.0008 time units for the time spent by requests in the system.

The analysis shows that in the first case, when the number of PMs changes from 3 to 5, the nature of the density distribution of the residence time T_U and waiting time T_W of requests does not change (see Fig. 3). Note that for clarity of histograms, it is desirable to have a large number of frequency intervals.

To obtain an objective picture, it is necessary to have a large sample of random variables, which is not always possible or advisable. The values of the lengths and number of frequency intervals are selected experimentally during several implementations of the simulation model or based on the expected values of the mathematical expectation and standard deviation of the corresponding random variable.

2.Requests received by the ISS are subject to an exponential distribution, and the service time is subject to a uniform distribution law.

In the second case, the results of a simulation model of the functioning of the ISS were obtained - reports (fragments of reports are shown in Fig. 4, on the basis of which Table 2 was created) and histograms of the distribution densities of the residence time T_U and waiting time T_W of requests, at $N = \overline{2,5}$ (Fig. 5).

Table 2 reflects the dynamics of changes in the number of requests in the PM, the average queue length and the PM utilization rate depending on the number of PM (N) during the simulation for the second case.

Table 2

Dynamics of changes in system characteristics depending on the number of MHs for the second case

Number of PM	Number of requests to the PM (ENTRIES)	Average queue length (AVE.C)	PM utilization rate (UTIL)
2	100002	2.000	1.000
3	100003	2.064	0.688
4	100002	2.056	0.514
5	100002	2.053	0.411

Analysis of the dynamics of changes in these characteristics shows that with an increase in the number of PMs from 2 to 5:

- as in the first case, the number of requests in the PM remains almost unchanged, i.e. the difference is 1;
- the average queue length increases, and the difference is 0.064;
- the coefficient of utilization of the PM decreases, and the difference is 0.589.

The analysis shows that in the second case, when the number of MHs changes from 3 to 5, the nature of the density distribution of the residence time T_U and waiting time T_W of requests does not change (see Fig. 5).

```
QUEUE              MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1             3080 3078 103079     5  1529.895     0.437      0.437    0

STORAGE            CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL                2    0    0    2   100002   1    2.000  1.000    0 3077

TABLE              MEAN     STD.DEV.       RANGE            RETRY FREQUENCY CUM.%
 T_W               0.437     0.242                            0
                                     _    -       0.000                9     0.01
                                  0.000   -       0.001                8     0.02
                                  0.001   -       0.001                9     0.03
                                  0.001   -       0.002               19     0.04
                                  0.002   -       0.002               11     0.06
                                  0.002   -       0.002               14     0.07
                                  0.002   -       0.003                9     0.08
                                  0.003   -       0.003                8     0.09
                                  0.003   -       0.004               11     0.10
                                  0.004   -   _                    99903   100.00
 T_U               0.437     0.242                            0
                                     _    -       0.001                6     0.01
                                  0.001   -       0.002               15     0.02
                                  0.002   -       0.002               25     0.05
                                  0.002   -       0.003               21     0.07
                                  0.003   -       0.004               17     0.09
                                  0.004   -       0.005               30     0.13
                                  0.005   -       0.006               47     0.18
                                  0.006   -       0.006               70     0.26
                                  0.006   -       0.007               88     0.35
                                  0.007   -                        89851   100.00
```

```
QUEUE              MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1               21    1 100003  54042     0.557     0.000      0.000    0

STORAGE            CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL                3    0    0    3   100003   1    2.064  0.688    0     0

TABLE              MEAN     STD.DEV.       RANGE            RETRY FREQUENCY CUM.%
 T_W               0.000     0.000                            0
                                     _    -       0.000            85244    85.24
                                  0.000   -       0.001            11138    96.38
                                  0.001   -       0.001             2714    99.09
                                  0.001   -       0.002              676    99.77
                                  0.002   -       0.002              176    99.95
                                  0.002   -       0.002               25    99.97
                                  0.002   -       0.003                6    99.98
                                  0.003   -       0.003                9    99.99
                                  0.003   -       0.004                6    99.99
                                  0.004   -   _                        8   100.00
 T_U               0.001     0.000                            0
                                     _    -       0.001            65006    72.27
                                  0.001   -       0.002            23400    98.28
                                  0.002   -       0.002             1465    99.91
                                  0.002   -       0.003               59    99.97
                                  0.003   -       0.004               15    99.99
                                  0.004   -       0.005               10   100.00
```

```
QUEUE              MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1                8    0 100002  82358     0.112     0.000      0.000    0

STORAGE            CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL                4    2    0    4   100002   1    2.056  0.514    0     0

TABLE              MEAN     STD.DEV.       RANGE            RETRY FREQUENCY CUM.%
 T_W               0.000     0.000                            0
                                     _    -       0.000            98663    98.66
                                  0.000   -       0.001             1293    99.95
                                  0.001   -       0.001               46   100.00
 T_U               0.001     0.000                            0
                                     _    -       0.001            84401    93.84
                                  0.001   -       0.002             5542   100.00
                                  0.002   -       0.002                3   100.00
```

```
QUEUE              MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1                7    0 100002  93823     0.029     0.000      0.000    0

STORAGE            CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL                5    3    0    5   100002   1    2.053  0.411    0     0

TABLE              MEAN     STD.DEV.       RANGE            RETRY FREQUENCY CUM.%
 T_W               0.000     0.000                            0
                                     _    -       0.000            99894    99.89
                                  0.000   -       0.001              107   100.00
                                  0.001   -       0.001                1   100.00
 T_U               0.001     0.000                            0
                                     _    -       0.001            88876    98.71
                                  0.001   -       0.002             1165   100.00
```

Fig.4. Fragments of reports for the first case, when $N=\overline{2,5}$

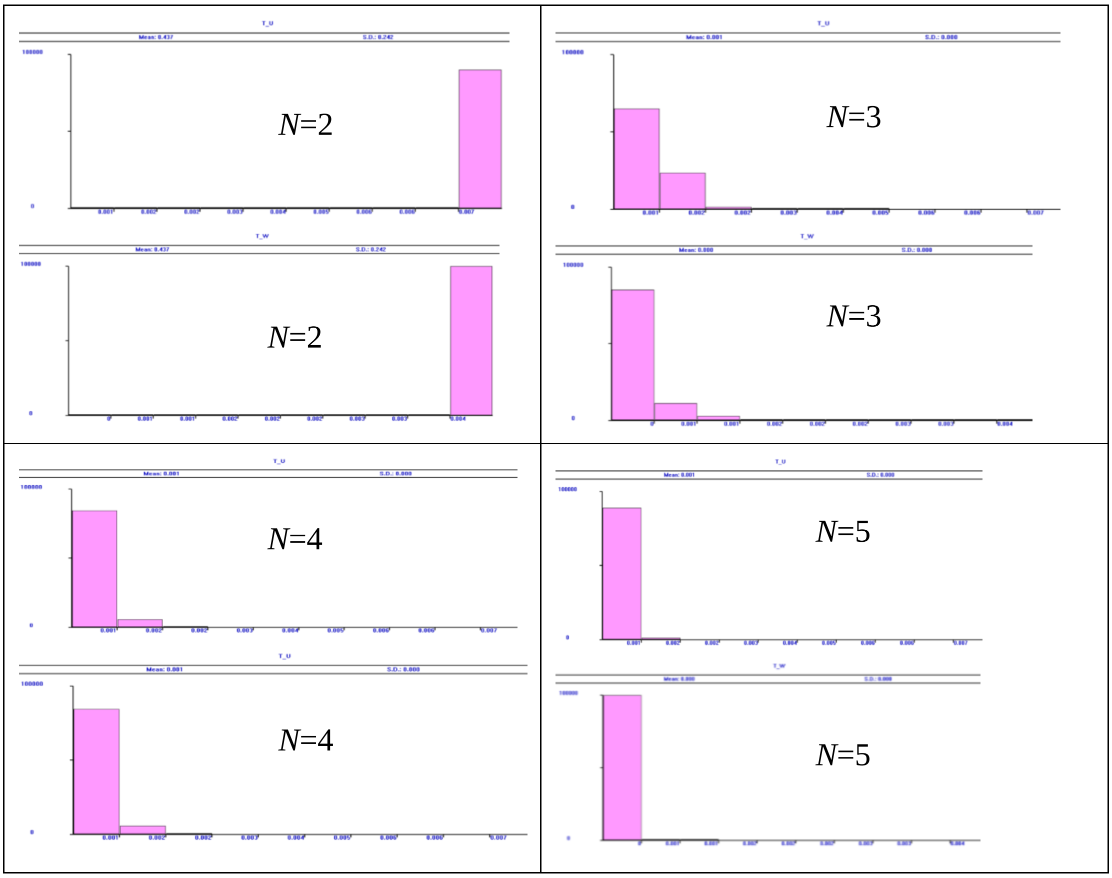


Fig.5. Histograms of distribution densities of residence time T_U and waiting time T_W *of requests for the second case, with* $N=\overline{2,5}$.

3. Receipts of requests to the ISS are subject to the exponential distribution law, and the service time is subject to the Erlang distribution law.

In the third case, the results of the ISS simulation model were obtained - reports (fragments of reports are shown in Fig. 6, on the basis of which Table 3 was created) and histograms of the density distribution of the residence time T_U and waiting time T_W of requests at $N = \overline{2,5}$ (Fig. 7).

Table 3 shows the dynamics of changes in the number of requests in the PM, the average queue length, and the coefficient of PM utilization from the number of PM (N) during the simulation for the third case.

Table 3

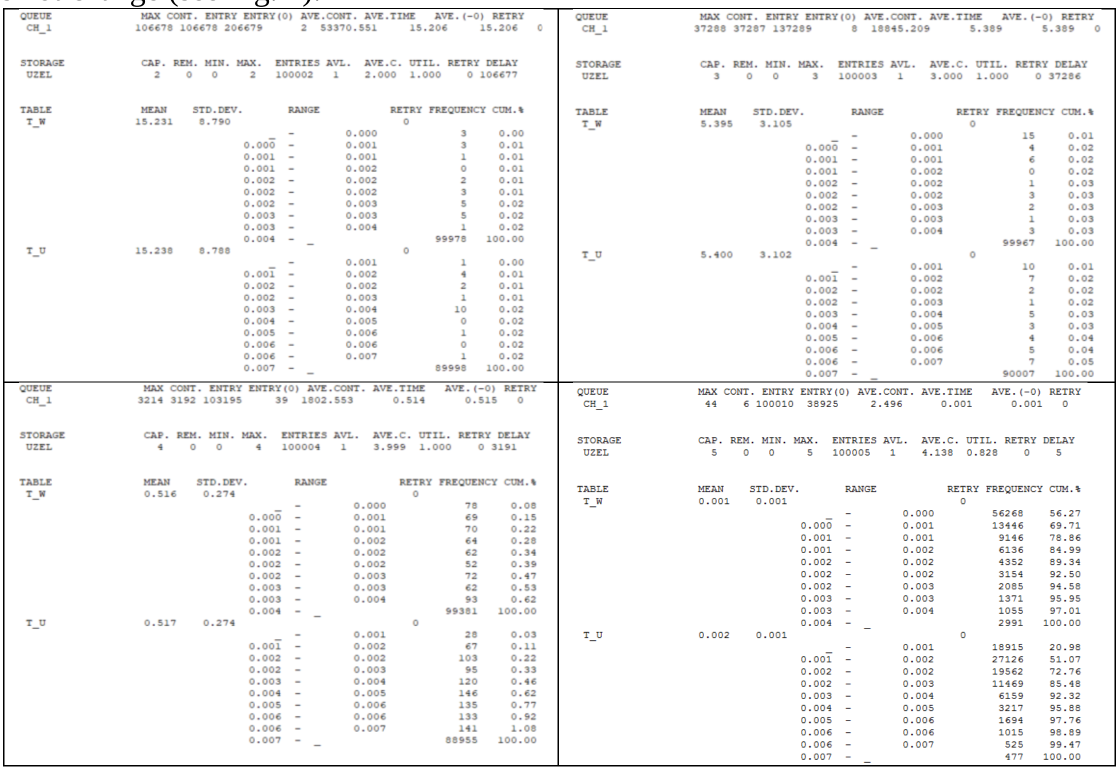
Dynamics of changes in the characteristics of the MH system for the third case

Number of PM	Number of requests to the PM (ENTRIES)	Average queue length (AVE.C)	PM utilization rate (UTIL)
2	100002	2.000	1.000
3	100003	3.000	1.000
4	100004	3.999	1.000
5	100005	4.138	0.828

Analysis of the dynamics of changes in these characteristics shows that with an increase in the number of PMs from 2 to 5:

- the number of requests in the PM increases slightly, and the difference is 3 requests;
- the average queue length increases, and the difference is 2.138;
- the coefficient of utilization of the PM decreases, and the difference is 0.172.

The analysis shows that in the third case, when the number of PMs changes from 2 to 4, the nature of the density distribution of the residence time T_U and waiting time T_W of requests does not change (see Fig. 7).



```
QUEUE             MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1          106678 106678 206679      2  53370.551     15.206     15.206   0

STORAGE           CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL               2    0    0    2   100002   1    2.000  1.000    0 106677

TABLE             MEAN    STD.DEV.       RANGE            RETRY FREQUENCY CUM.%
 T_W              15.231    8.790                           0
                                      _  -        0.000                3     0.00
                                  0.000  -        0.001                3     0.01
                                  0.001  -        0.001                1     0.01
                                  0.001  -        0.002                0     0.01
                                  0.002  -        0.002                2     0.01
                                  0.002  -        0.002                3     0.01
                                  0.002  -        0.003                5     0.02
                                  0.003  -        0.003                5     0.02
                                  0.003  -        0.004                1     0.02
                                  0.004  -  _                      99978   100.00
 T_U              15.238    8.788                           0
                                      _  -        0.001                1     0.00
                                  0.001  -        0.002                4     0.01
                                  0.002  -        0.002                2     0.01
                                  0.002  -        0.003                1     0.01
                                  0.003  -        0.004               10     0.02
                                  0.004  -        0.005                0     0.02
                                  0.005  -        0.006                1     0.02
                                  0.006  -        0.006                0     0.02
                                  0.006  -        0.007                1     0.02
                                  0.007  -  _                      89998   100.00
```

```
QUEUE             MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1           37288 37287 137289      8  18845.209      5.389      5.389   0

STORAGE           CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL               3    0    0    3   100003   1    3.000  1.000    0 37286

TABLE             MEAN    STD.DEV.       RANGE            RETRY FREQUENCY CUM.%
 T_W              5.395     3.105                           0
                                      _  -        0.000               15     0.01
                                  0.000  -        0.001                4     0.02
                                  0.001  -        0.001                6     0.02
                                  0.001  -        0.002                0     0.02
                                  0.002  -        0.002                1     0.03
                                  0.002  -        0.002                3     0.03
                                  0.002  -        0.003                2     0.03
                                  0.003  -        0.003                1     0.03
                                  0.003  -        0.004                3     0.03
                                  0.004  -  _                      99967   100.00
 T_U              5.400     3.102                           0
                                      _  -        0.001               10     0.01
                                  0.001  -        0.002                7     0.02
                                  0.002  -        0.002                2     0.02
                                  0.002  -        0.003                1     0.02
                                  0.003  -        0.004                5     0.03
                                  0.004  -        0.005                3     0.03
                                  0.005  -        0.006                4     0.04
                                  0.006  -        0.006                5     0.04
                                  0.006  -        0.007                7     0.05
                                  0.007  -  _                      90007   100.00
```

```
QUEUE             MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1             3214 3192 103195     39   1802.553      0.514      0.515   0

STORAGE           CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL               4    0    0    4   100004   1    3.999  1.000    0 3191

TABLE             MEAN    STD.DEV.       RANGE            RETRY FREQUENCY CUM.%
 T_W              0.516     0.274                           0
                                      _  -        0.000               78     0.08
                                  0.000  -        0.001               69     0.15
                                  0.001  -        0.001               70     0.22
                                  0.001  -        0.002               64     0.28
                                  0.002  -        0.002               62     0.34
                                  0.002  -        0.002               52     0.39
                                  0.002  -        0.003               72     0.47
                                  0.003  -        0.003               62     0.53
                                  0.003  -        0.004               93     0.62
                                  0.004  -  _                      99381   100.00
 T_U              0.517     0.274                           0
                                      _  -        0.001               28     0.03
                                  0.001  -        0.002               67     0.11
                                  0.002  -        0.002              103     0.22
                                  0.002  -        0.003               95     0.33
                                  0.003  -        0.004              120     0.46
                                  0.004  -        0.005              146     0.62
                                  0.005  -        0.006              135     0.77
                                  0.006  -        0.006              133     0.92
                                  0.006  -        0.007              141     1.08
                                  0.007  -  _                      88955   100.00
```

```
QUEUE             MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1              44     6 100010  38925      2.496      0.001      0.001   0

STORAGE           CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL               5    0    0    5   100005   1    4.138  0.828    0     5

TABLE             MEAN    STD.DEV.       RANGE            RETRY FREQUENCY CUM.%
 T_W              0.001     0.001                           0
                                      _  -        0.000            56268    56.27
                                  0.000  -        0.001            13446    69.71
                                  0.001  -        0.001             9146    78.86
                                  0.001  -        0.002             6136    84.99
                                  0.002  -        0.002             4352    89.34
                                  0.002  -        0.002             3154    92.50
                                  0.002  -        0.003             2085    94.58
                                  0.003  -        0.003             1371    95.95
                                  0.003  -        0.004             1055    97.01
                                  0.004  -  _                       2991   100.00
 T_U              0.002     0.001                           0
                                      _  -        0.001            18915    20.98
                                  0.001  -        0.002            27126    51.07
                                  0.002  -        0.002            19562    72.76
                                  0.002  -        0.003            11469    85.48
                                  0.003  -        0.004             6159    92.32
                                  0.004  -        0.005             3217    95.88
                                  0.005  -        0.006             1694    97.76
                                  0.006  -        0.006             1015    98.89
                                  0.006  -        0.007              525    99.47
                                  0.007  -  _                        477   100.00
```

Fig.6. Fragments of reports for the first case, when $N = \overline{2,5}$

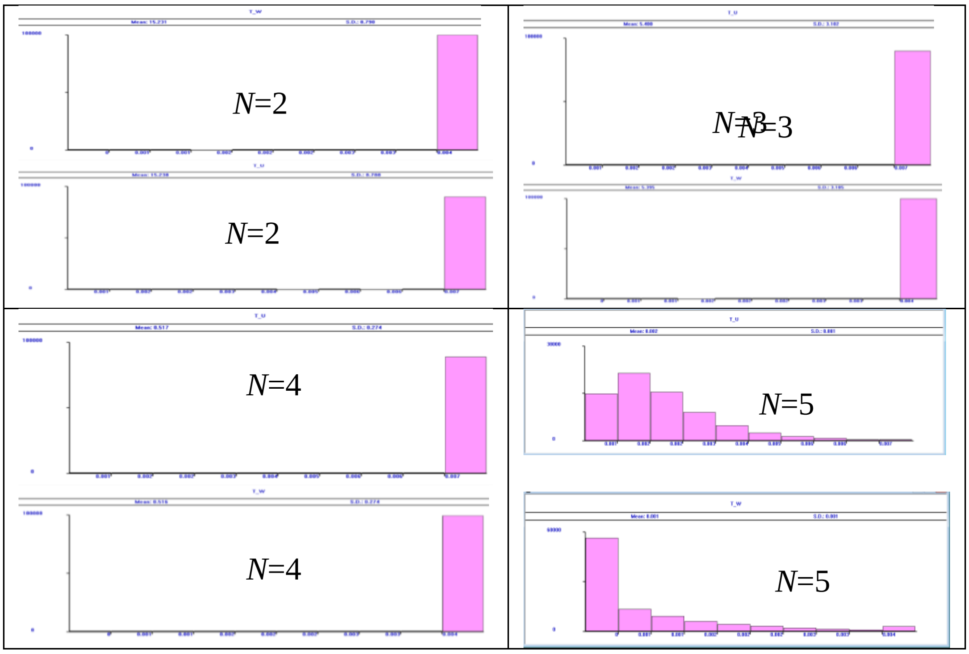
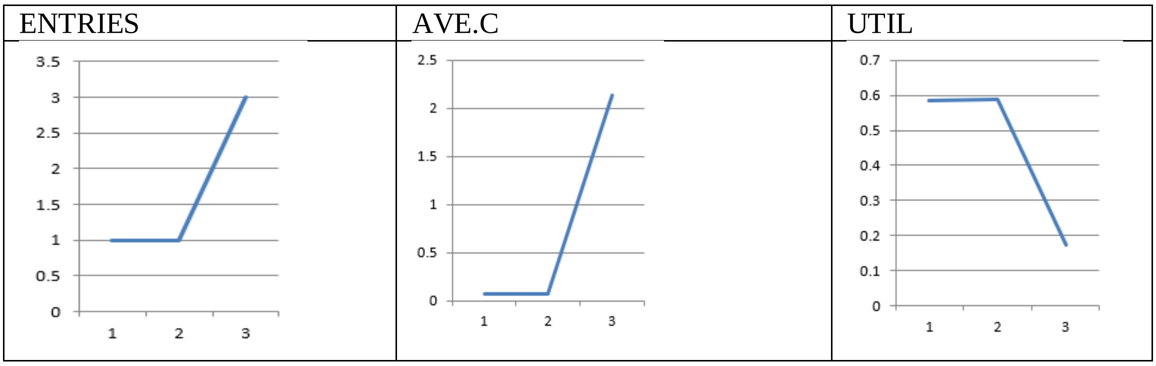


Fig.7. Histograms of distribution densities of residence time T_U *and waiting time* T_W *of requests for the third case, with* $N = \overline{2,5}$.

Based on Tables 1-3, the dynamics of changes in the differences in the number of requests in the PM, the average queue length and the PM utilization rate for three cases at $N = \overline{2,5}$.



a) в) c)

Fig. 8. Dynamics of changes in the differences in the number of requests in the PM (a), average queue lengths (b), and PM utilization rates (c) for three cases at $N = \overline{2,5}$.

The results obtained from Tables 1-3 and Fig. 8 show that with an increase in the number of PMs from 2 to 5 for three cases:

– the nature of the change in the differences in the number of requests in the PM is 1; 1 and 3;
– the nature of the change in the differences in the average queue length is 0.071; 0.064;2.138;
– the nature of the change in the differences in the utilization rate of the PM is 0.586; 0.589; 0.172.

4. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

The current problem of developing an algorithm and simulation model is being solved, the results of the simulation model are analyzed to determine the main characteristics of the ISS, providing the opportunity to completely close, with the help of a security system, all possible channels of manifestation of threats, by ensuring control of the transition of all requests of the UA through the PM.

The scientific novelty of the results obtained lies in the fact that for the first time an algorithm and simulation models were proposed and developed, a methodology for the development of ISS based on the analysis of the structural and temporal characteristics of the ISS from the UA, as a single-phase multi-channel QS with an unlimited volume of BM with wide values of input and output parameters.

The experiments carried out based on the developed algorithm and model confirmed the expected results when analyzing the characteristics of the ISS from the UA. The practical significance of the results obtained lies in the fact that these results can be used for the practical construction of new or modification of existing ISS in corporate service networks for various purposes, including higher educational institutions.

This work is one of the approaches to generalizing the problems under consideration for systems with an unlimited volume of BM.

Prospects for further research include research and development of the principles of hardware and software implementation of ISS from UA with an unlimited volume of BM in corporate service networks.

REFERENCES (TRANSLATED AND TRANSLITERATED)

[1] B.G. Ismailov. Modelling and analysis of the security system information in service networks. *Problemi ínformatizatsíї ta upravlínnya.*Vol.1, №69,P.46-53..2022. doi:10.1 837 2/2073-4751.6 9.16812. (in English).

[2] L.Fan, Y.Wang, X.Cheng, J.Li, S.Jin. Privacy theft malware multi-process collaboration analysis. *Security and Communication Networks.*8 (1): pp.51– 67.2013. doi:10.10 02/sec. 705. (in English).

[3] E.Gal-Or, and A.Ghose, The Economic Incentives for Sharing Security Information. *Information Systems Research*, 16, pp.186-208. 2005. https://doi.org/10.1287/isre.1050.0053. (in English).

[4] L.A. Gordon, M. P. Loeb. The Economics of Information Security Investment. *ACM Transactions on Information and System Security*. 5 (4): November 2002, pp.438–457. doi:10.1145/58 127 1.5812 74. S2CID 1500788. (in English).

[5] K. Matsuura, Productivity Space of Information Security in an Extension of the Gordon-Loeb's Investment Model. In: Johnson, M.E., Ed., *Managing Information Risk and the Economics of Security*, Springer, Boston, pp.99-119. 2009. https://doi.org/10.1007/978-0-387-09762-6_5. (in English).

[6] S. E.Fienberg, A. B. Slavković, Data Privacy and Confidentiality. *International Encyclopedia of Statistical Science*, pp. 342–345, 2011. doi:10.1007/978-3-642-04898-2_202. (in English).

[7] V. Pevnev. Model Threats and Ensure the Integrity of Information. *Systems and Technologies*. 2 (56), pp.80-95. 2018. doi:10.32836/2521-66 43-2018.2-56.6. (in English).

[8] M. Ezhei, and B.T.Ladani, Information Sharing vs. Privacy: A Game Theoretic Analysis. *Expert Systems with Applications*, 88, 327-337. 2017. https://doi.org/10.1016/j.eswa.2017.06.042. (in English).

[9] Fowler Kevvie Developing a Computer Security Incident Response Plan. Data Breach Preparation and Response, Elsevier, pp. 49–77, retrieved June 5, 2021.doi:10.1016/b978-0-12-803451-4.00003-4. (in English).

[10] D. B. Parker. A Guide to Selecting and Implementing Security Controls. *Information Systems Security*. 3 (2): pp.75-86. 1994.doi:10.1080/10658989 4093 42459. (in English).

[11] H.S.Venter, J.H.P. Eloff, A taxonomy for information security technologies. *Computers & Security*. 22 (4): pp.299-307. 2003. doi: 10. 1016/S0167-4048(03)00406-1. (in English).

[12] Authorization and approval program. Internal Controls Policies and Procedures, Hoboken, NJ, US: John Wiley & Sons, Inc., October 23, 2015pp. 69–72, retrieved June1, 2021.doi:10.1002/9781119 20 39 64.ch10.(in English).

[13] A. Almehmadi, El-Khatib Kh. Proceedings of the 6th International Conference on Security of Information and Networks. Sin '13.US: ACMPress. New York, 2013. pp.363-367. doi:10.1145/2 52 3514.25 23612. (in English).

[14] G.Loukas, G.Oke, Protection Against Denial of Service Attacks: A Survey. Comput. J. 53 (7): September 2018 [August 2009] pp.1020–1037. Archived from the original on March 24, 2012.Retrieved August 28, 2015.doi: 10.1 093/com jnl/bxp078. (in English).

[15] T. Keyser. Security policy.The Information Governance Toolkit, *CRC Press*, pp. 57-62, April 19 2018.retrieved May 28, 2021. doi:10.1201/978 1315385488-13. (in English).

[16] J. E. Boritz. IS Practitioners' Views on Core Concepts of Information Integrity. *International Journal of Accounting Information Systems*. Elsevier 6 (4): pp.260–279. 2005.doi:10.1016/ j. accinf. 2005. 07.001. (in English).

Text of the article was accepted by Editorial Team 22.06.2024

АНАЛІЗ РЕЗУЛЬТАТІВ ІМІТАЦІЙНОГО МОДЕЛЮВАННЯ СИСТЕМИ ЗАХИСТУ ІНФОРМАЦІЇ У КОРПОРАТИВНИХ МЕРЕЖАХ ЗАКЛАДІВ ВИЩОЇ ОСВІТИ

Вагіф Касумов
доктор технічних наук, професор,
завідувач кафедри «Комп'ютерні технології» Азербайджанського технічного університету, м. Баку, Азербайджан
ORCID ID 0000-0003-3192-4225
vaqif.qasimov@aztu.edu.az

Балами Ісмайлів
доктор технічних наук,
професор кафедри «Комп'ютерні системи та програмування» Національної академії авіації, м. Баку, Азербайджан
ORCID ID 0009-0002-3013-9161
balemi@rambler.ru

Анотація. Аналіз показує, що недостатній рівень інформаційної безпеки мереж обслуговування є основною причиною величезних збитків для підприємств. Незважаючи на появу низки робіт щодо вирішення цієї проблеми, єдиної системи оцінки інформаційної безпеки на сьогоднішні немає. Це свідчить про те, що ця проблема ще недостатньо вивчена та актуальна. Ця робота є одним із кроків до створення системи оцінки інформаційної безпеки в мережах обслуговування.
Метою роботи є розробка алгоритму та імітаційної моделі, аналіз результатів імітаційної моделі для визначення основних характеристик системи захисту інформації (СЗІ), що забезпечує можливість повністю закрити всі можливі канали загроз шляхом контролю всіх несанкціонованих запитів доступу (НЗД) через механізм захисту (МЗ).
Для вирішення задачі застосовано метод моделювання з використанням принципів систем масового обслуговування (СМО). Цей метод дає можливість отримати основні характеристики СЗІ від НЗД з необмеженим обсягом буферної пам’яті (БП). Запропоновано моделі, алгоритм і методологію розробки СЗІ з НЗД, яка розглядається як однофазна багатоканальна СМО з необмеженим обсягом БП. Процес отримання результатів моделювання було реалізовано в системі моделювання GPSS World і проведено порівняльний аналіз основних характеристик СЗІ для різних законів розподілу вихідних параметрів. Водночас НЗД запити були найпростішими потоками, а час обслуговування підпорядковувався експоненційному, константному та Ерланговому законам розподілу.
Проведені експерименти на основі запропонованих моделей та алгоритму аналізу характеристик СЗІ з НЗД як однофазної багатоканальної СМО з необмеженим часом очікування запитів у черзі підтвердили очікувані результати. Отримані результати можуть бути використані для побудови нових або модифікації існуючих ІКС у корпоративних мережах для обслуговування об’єктів різного призначення. Дана робота є одним з підходів до узагальнення задач, що розглядаються, для систем з необмеженим об’ємом БП. Перспективи подальших досліджень полягають у дослідженні та розробці принципів апаратно-програмної реалізації СЗІ в мережах обслуговування.

Ключові слова: несанкціоновані запити доступу (НЗД); системи захисту інформації (СЗІ); інформаційна безпека; системи масового обслуговування (СМО); механізм захисту (МЗ); імітаційне моделювання.