# МАТЕМАТИЧНЕ ТА КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ

# MATHEMATICAL AND COMPUTER MODELING

UDC 621.394.74:519.872

## ANALYSIS OF THE RESULTS OF SIMULATION MODELING OF THE INFORMATION SECURITY SYSTEM AGAINST UNAUTHORIZED ACCESS IN SERVICE NETWORKS

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### ABSTRACT

**Context.** An analysis of the service network shows that insufficient information security in service networks is the cause of huge losses incurred by corporations. Despite the appearance of a number of works and materials on standardization, there is currently no unified system for assessing information security in the field of information security. It should be noted that existing methods, as well as accumulated experience in this area, do not completely overcome these difficulties. This circumstance confirms that this problem has not yet been sufficiently studied and, therefore, remains relevant. The presented work is one of the steps towards creating a unified system for assessing information security in service networks.

**Objective.** Development of an algorithm and simulation model, analysis of simulation results to determine the key characteristics of the Information Security System, providing the capability for complete closure, through the security system, of all potential threat channels by ensuring control over the passage of all unauthorized access requests through defense mechanisms.

**Method.** To solve the problem, a simulation method was applied using the principles of queuing system modeling. This method makes it possible to obtain the main characteristics of the Information Security System from the unauthorized access with a limited amount of buffer memory.

**Results.** Algorithms, models, and methodology have been developed for the development of Information Security System from unauthorized access, considered as a single-phase multi-channel queuing system with a limited volume of buffer memory. The process of obtaining model results was implemented in the General Purpose Simulation System World modelling system, and comparative assessments of the main characteristics of the Information Security System were carried out for various laws of distribution of output parameters, i.e., in this case, unauthorized access requests are the simplest flows, and the service time obeys exponential, constant, and Erlang distribution laws.

**Conclusions.** The conducted experiments based on the algorithm and model confirmed the expected results when analyzing the characteristics of the Information Security System from the unauthorized access as a single-phase multi-channel queuing system with a limited waiting time for requests in the queue. These results can be used for practical construction of new or modification of existing Information Security System s in service networks of objects of various purposes. This work is one of the approaches to generalizing the problems under consideration for systems with a limited volume of buffer memory. Prospects for further research include research and development of the principles of hardware and software implementation of Information Security System in service networks.

**KEYWORDS:** unauthorized access, information security systems, information security, queuing systems, defense mechanism, simulation modeling.

### ABBREVIATIONS

BM is a Buffer Memory;

DM is a Defense Mechanism;

GPSS World is a General Purpose Simulation System (latest version of GPSS);

ISS is an Information Security System;

QS is a Queuing System;

UA is an Unauthorized Access.

### NOMENCLATURE

AVE.C is an Average Queue Length;

CUM.% is a Cumulative Percentage, expressed as a percentage of the total number of random values;

ENTRIES is a number of requests in DM;

FREQUENCY is the number of random values falling within the given interval;

$L_q$ is an average queue length;

$L^0$ is the permissible limit values $L_q$;

$M$ is a mathematical expectation symbol;

MEAN is a mean value of the corresponding random variable;

$N$ is a number of DMs in ISS;

$N_0$ is the permissible limit values $N$;


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$p_1$ is a probability of blocking UA requests;

$p_2$ is a probability of UA requests bypassing protected resources;

RANGE is a lower and upper bound of the frequency interval;

RETRY is a number of requests waiting for the fulfillment of a specific condition depending on the state of this table;

STD.DEV is a Standard Deviation of the random variable;

$T\_U$ is a time of requests' stay in the system;

$T\_W$ is a time of requests' waiting in the queue;

UTIL is a Utilization Coefficient of DM;

$\lambda$ is an intensity of various threats at the entrance of ISS;

$\lambda_0$ is the permissible limit values $\lambda$;

$\mu$ is an intensity of servicing UA requests;

$\mu_0$ is the permissible limit values $\mu$;

$\tau_0$ is a service delays;

$\rho$ is a normalized intensity.

## INTRODUCTION

This work is dedicated to approaches in researching ISS in service networks, addressing security issues characteristic of systems with limited BM capacities. When addressing security issues in service networks, the primary determinant is the security class of the network, defining a set of DMs that constitute the hardware or software part implemented in the network. In service networks, intentional UA requests are often received alongside regular requests, targeting confidential information from illegal users, which can lead to network disruptions. It should be noted that DMs, influencing the entire information security process, may operate in constant information interaction with other elements of the ISS. The operation of DMs is described by four possible states: operational, non-operational, diagnosed, and restored. In ISS, the possibility of an undesirable event related to the reliability characteristics of DMs, leading to various types of losses, is considered a risk. However, approaches associated with the risk arising from the reliability characteristics of DMs are not considered in this work, i.e., it is assumed that all DMs are reliable.

The task related to the security problem in service networks is addressed by examining the ISS, ensuring the complete closure of all possible channels of threat manifestation through the security system. This is achieved by controlling the passage of all UA requests through DM.

**The object of the study** is an ISS against UA with a limited amount of BM in service networks.

**The subject of the study** is to determine the structure of the object, i.e. determination of the main characteristics of the system – security of information from UA with a limited amount of BM in service networks.

**The goal of the work** is to develop an algorithm and simulation model, analyze the results of the simulation model, allowing us to determine the main characteristics of an ISS against UA with a **limited** amount of BM in service networks.

## 1 PROBLEM STATEMENT

The structure of ISS with limited BM is considered (Fig. 1), where all input streams are directed to DM for servicing. As noted earlier, the security system allows for the complete closure of all possible channels of threat manifestation by controlling the passage of all UA requests through DM. It is assumed that the examined ISS structure ensures maximum information security for service networks. This structure constitutes a hardware and software complex interacting with random event streams, which are conditioned by the actions of attackers, improper access rights distribution, unauthorized software usage, as well as errors in identification and authentication software and technical complexes.

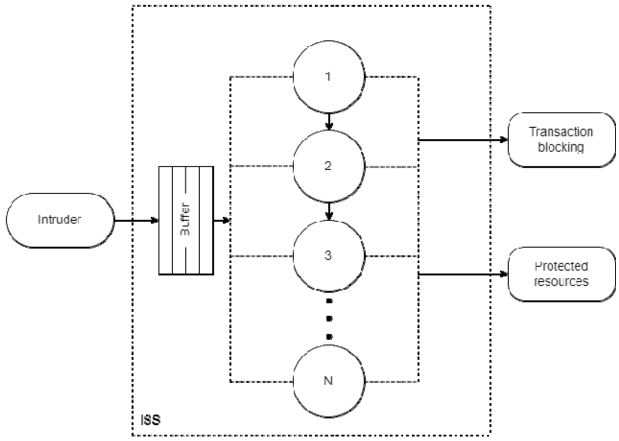

Figure 1 – General Structure of ISS with Limited BM

The assumption is that the intruder (attacker, UA requests) at the system's entrance generates various threats with intensity $\lambda$. The ISS consists of $N$ DMs that introduce delays $\tau_0 = 1/\mu$ in service. If we consider the intruder block as an information source and DMs as devices operating in parallel, the mathematical model of the ISS can be regarded as a single-phase, multi-channel QS with limited BM. Taking into account the complex nature of UA request servicing (filtering UA requests, detection and classification of UA attempts, blocking or allowing UA requests to access protected resources, etc.), Poisson formulas are suggested as the probability loss function for UA requests due to system overload in [1]:

$$P(\lambda, \mu, N) = \sum_{j=N}^{\infty} \left(\rho^j / j!\right) e^{-\rho}.$$

Then, the problem of determining the optimal values of ISS characteristics can be formulated as the minimization of the mathematical expectation of the probability loss function for UA requests due to system overload:


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$$M\left[\sum_{j=N}^{\infty}\left(\rho^{j}/j!\right)e^{-\rho}\right]\rightarrow \min$$

with $\lambda \geq \lambda_0$, $\mu \geq \mu_0$, $N \geq N_0$ , $L_q \leq L^0$,

where $\rho = \lambda/\mu$. Problems related to insufficient information security in service networks, and the task of determining optimal ISS characteristics against UA for various cases, have been considered and analytically solved in [1] and optimal values for QS characteristics with and without waiting requests in the queue have been obtained.

However, for a detailed analysis of ISS characteristics against UA across a wide range of input and output parameters, it is preferable to utilize simulation modeling methods, considering it as a single-phase, multi-channel QS both with and without waiting. Given the volume of obtained results from the simulation model, we will limit the discussion here to the analysis of the simulation model results for a QS with limited waiting requests, encompassing a broad range of input and output parameters.

Thus, based on the presented structure of the ISS, the task in this work is to analyze the results of simulation modeling of a single-phase multi-channel QS with limited BM. To achieve this, using simulation modeling, it is necessary to determine the structural and temporal characteristics of the ISS within the specified values of concurrently operating service devices (DMs).

## 2 LITERATURE REVIEW

Analysis and accumulated experience demonstrate that insufficient information security in service networks leads to significant losses for corporations. This underscores the high importance of the information security problem. An analysis of the current state of the issue in the field of information security and the development of ISS reveals serious challenges, largely stemming from the absence of a unified system for assessing information security. Such a system would enable a quantitative evaluation during the design and operation of service networks [2–8]. It is worth noting, that due to a lack of sufficient experience in designing ISS, tasks related to its construction must be addressed at the early stages of service network design.

Currently, given the increasing number of scientific studies and companies specializing in information security in service networks, this problem is insufficiently explored [4–11, 13]. It should be noted that one of the most obvious causes of ISS violation is intentional UA requests for confidential information by illegal users, followed by undesirable manipulations with this information [1, 2,12]. The effectiveness of information security protection in service networks is primarily determined by the service network's security class [1, 2, 11, 14–16], which defines the set of DMs implemented in the network.

In [1], due to the fact that the security system fails to completely close all possible threat channels, a structure for the ISS was proposed. Unlike existing structures, in this framework, each input stream is provided with a DM for maintenance.

In the work [1], a structure for the ISS with losses is proposed, featuring both limited and unlimited BM. This structure ensures maximum information security in service networks by controlling the passage of all UA requests through DMs. In contrast to [1], an analysis of the simulation model results for ISS with limited BM is conducted here, encompassing a broad range of input and output parameters.

## 3 MATERIALS AND METHODS

To determine the characteristics of the ISS that allow it to operate within limited resources, it is assumed that the input flow of information, i.e., UA requests, is Poisson distributed, and the service time follows exponential, constant, and Erlang distribution laws. Algorithms for the simulation model of the service process have been developed for three cases to adequately describe the operation of the ISS against UA:

1. Incoming requests to the ISS and service time follow an exponential distribution.
2. Incoming requests to the ISS follow an exponential distribution, while the service time follows a uniform distribution.
3. Incoming requests to the ISS follow an exponential distribution, while the service time follows an Erlang distribution.

The developed algorithm for the operation of the ISS against UA includes the following steps:

– setting the minimum permissible limit values for the number of concurrently operating service devices (DMs) and the maximum permissible limit values for the queue length, defining the BM volume;

– to conduct a detailed analysis of the properties of the investigated system, a table structure is organized for queue waiting time and request residence time. An upper limit for the first frequency interval is specified, along with the values for all other frequency intervals and the quantity of frequency intervals. The goal here is to build histograms of the probability density function for the waiting time in the queue and the residence time of requests in the system based on the accumulation of the frequency of occurrence of random variables within the specified frequency intervals;

– when a request is received, the system checks for available places in the queue. If there is no available space in the queue, the request is rejected and exits the system;

– otherwise, if all DMs are occupied, the UA request waits in the system's BM queue until one of the DMs becomes available provided there is free space in the BM.

– upon the release of one of the DMs, the UA request enters this available DM, and the process of filtering UA requests, detecting, and classifying UA attempts takes place. As a result, the initial UA stream is thinned out with certain probabilities $p_1$, $p_2 = 1 - p_1$ forming an output stream, in other words, with a probability of $p_1$ block-


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ing occurs, while with a probability of $p_2$ UA requests are allowed to pass through to the protected resources.

**Note 1.** The values of probabilities $p_1$, $p_2$ are determined based on statistical analysis.

Based on the proposed algorithm covering three cases of ISS functioning against UA as single-phase, multi-channel QS with a limited buffer size, simulation models were developed using the GPSS World modeling language. For $N = \overline{2,5}$ during the simulation the model allows you to determine such characteristics as ENTRIES, UTIL, AVE.C, MEAN, STD.DEV, RANGE, RETRY, FREQUENCY, CUM.%.

## 4 EXPERIMENTS

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

1. Incoming requests to the ISS and service time follow an exponential distribution.

In the first case, the results of a simulation model of the functioning of the information system were obtained – reports and histograms of the distribution densities of the residence time $T\_U$ and waiting time $T\_W$ of requests, with $N = \overline{2,5}$ (see Appendix A, Fig. A.1–A.8).

Based on the obtained reports, Table 1 was created, providing the dynamics of changes in the number of requests in the DM, the average queue length, and the utilization coefficient of the DM depending on the number of DM ( $N$ ) during the modeling period for the first case.

Table 1 – Dynamics of changes in characteristics depending on the number of DMs for the first case

| The number of DM | The number of requests in the DM | The average queue length | The utilization coefficient of the DM |
|---|---|---|---|
| 2 | 90266 | 1.866 | 0.933 |
| 3 | 99605 | 2.047 | 0.682 |
| 4 | 99989 | 2.056 | 0.514 |
| 5 | 100002 | 2.070 | 0.414 |

The analysis of the dynamics of these parameters shows that with an increase in the number of DM from 2 to 5:

– the number of requests in DM increases, with a difference of 9736 requests;

– the average queue length increases, with a difference of 0.204;

– the utilization coefficient of DM decreases, with a difference of 0.519.

In the models, 10 frequency intervals were chosen for building histograms, and the length of frequency intervals was selected as 0.0004 time units for waiting time in the queue and 0.0008 time units for the service time. The analysis conducted shows that in the first case, with a change in the number of DM from 3 to 5, the characteristics of the density distribution of the residence time $T\_U$ and waiting time $T\_W$ of requests do not change.

**Note 2.** 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 and feasible.

**Note 3.** The values of interval lengths and the number of frequency intervals are selected experimentally during several runs of the simulation model or based on assumed values of the mean and standard deviation of the corresponding random variable.

2. The requests entering the ISS follow an exponential distribution, while the service time adheres to a uniform distribution.

In the second case, the results of a simulation model of the functioning of the ISS were obtained – reports and histograms of the distribution densities of the residence time and waiting time of requests, with $N = \overline{2,5}$ (see Appendix B, Fig. B.1–B.8).

Based on the obtained reports, Table 2 was created, providing the dynamics of changes in the number of requests in the DM, the average queue length, and the utilization coefficient of the DM depending on the number of DM ( $N$ ) during the modeling period for the second case.

Table 2 – Dynamics of changes in characteristics depending on the number of DMs for the second case

| The number of DM | The number of requests in the DM | The average queue length | The utilization coefficient of the DM |
|---|---|---|---|
| 2 | 93922 | 1.932 | 0.966 |
| 3 | 99980 | 2.061 | 0.687 |
| 4 | 100002 | 2.056 | 0.514 |
| 5 | 100002 | 2.053 | 0.411 |

The analysis of the dynamics of these parameters shows that with an increase in the number of DM from 2 to 5:

– the number of requests in DM increases, with a difference of 6080 requests;

– the average queue length increases, with a difference of 0.121;

– the utilization coefficient of DM decreases, with a difference of 0.555.

The analysis conducted shows that in the first case, with a change in the number of DM from 3 to 5, the characteristics of the density distribution of residence time $T\_U$ and waiting time $T\_W$ of requests do not change.

3. The incoming requests to the ISS follow an exponential distribution, while the service time follows an Erlang distribution.

In the third case, the results of the ISS simulation model were obtained – reports and histograms of the density distribution of the residence time $T\_U$ and the waiting time $T\_W$ of requests at $N = \overline{2,5}$ (see Appendix C, Fig. C.1–C.8).


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Based on the obtained reports, Table 3 was created, providing the dynamics of changes in the number of requests in the DM, the average queue length, and the utilization coefficient of the DM depending on the number of DM ( $N$ )during the modeling period for the third case.

Table 3 – Dynamics of changes in characteristics depending on the number of DMs for the third case

| The number of DM | The number of requests in the DM | The average queue length | The utilization coefficient of the DM |
|---|---|---|---|
| 2 | 91907 | 1.898 | 0.949 |
| 3 | 99633 | 2.053 | 0.684 |
| 4 | 100003 | 2.061 | 0.515 |
| 5 | 100002 | 2.058 | 0.412 |

The analysis of the dynamics of these parameters shows that with an increase in the number of DM from 2 to 5:

– the number of requests in DM increases, with a difference of 8095 requests;

– the average queue length increases, with a difference of 0.159;

– the utilization coefficient of DM decreases, with a difference of 0.537.

The analysis conducted shows that in the first case, with a change in the number of DM from 3 to 5, the characteristics of the density distribution of the residence time $T\_U$ and waiting time $T\_W$ of requests do not change.

Based on Tables 1–3, the dynamics of changes in the differences in the number of requests in the DM, average queue length, and the utilization coefficient of the DM for three cases with $N = \overline{2,5}$ , and the nature of these differences are presented in Fig. 2–4.

ENTRIES

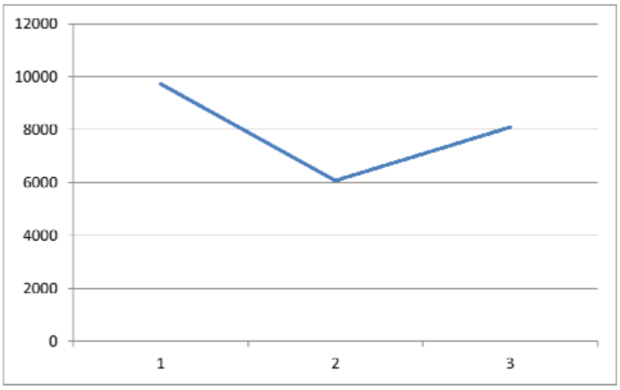


Figure 2 – The nature of the change in the differences in the number of requests in the DM for three cases with $N = \overline{2,5}$

AVE.C

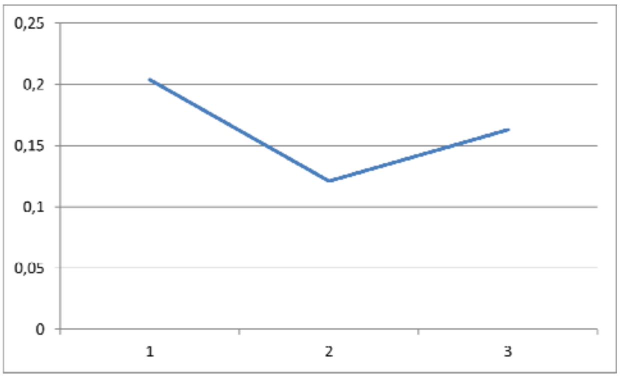


Figure 3 – The nature of changes in the differences in the average queue length for three cases with $N = \overline{2,5}$

UTIL

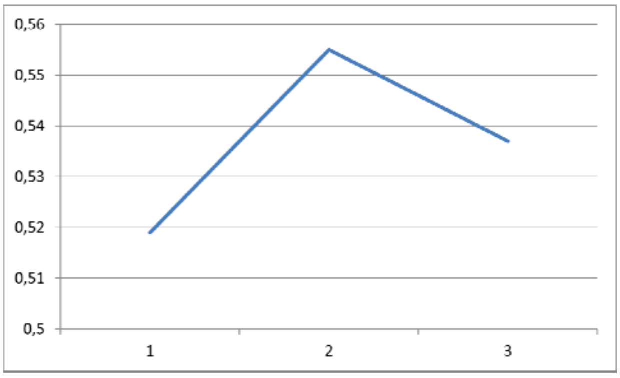


Figure 4 – The nature of changes in the differences in the coefficients of use of DM for three cases with $N = \overline{2,5}$

The results obtained from Table 1–3 and Fig. 2–4 show that with an increase in the number of DM from 2 to 5 in three cases:

– the nature of the change in the differences in the number of requests in the DM is 9736, 6080 and 8095;

– the nature of the change in the differences in the average queue length is 0,204; 0,121 and 0.163;

– the nature of the change in the differences in the utilization coefficient DM is 0.519; 0.555 and 0.537.

## CONCLUSIONS

The current task of developing an algorithm and simulation model, along with the analysis of simulation model results to determine the key characteristics of the ISS, is being addressed. This aims to provide the capability for complete closure, through the security system, of all potential threat channels by ensuring control over the transition of all UA through the DM.

**The scientific novelty** of the obtained results lies in the fact that, for the first time, algorithms, and simulation models, as well as a methodology for developing the ISS, have been proposed and developed based on the analysis of structural and temporal characteristics of ISS from UA. This includes treating it as a single-phase multi-channel queueing system with limited waiting time in the queue across a wide range of input and output parameters. The experiments conducted using the algorithm and model


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confirmed the expected results when analyzing the characteristics of the ISS from UA.

**The practical significance** of the results lies in their applicability for the practical construction of new or modification of existing ISS in networks for various purposes. This work represents one of the approaches to generalizing the considered problems for systems with a limited BM.

**Prospects for** further **research** include the exploration and development of hardware and software implementation principles for ISS from UA with a limited BM in service networks.

## ACKNOWLEDGMENTS

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## Appendix A

The first case's simulation model's results of the ISS's operation.

```
QUEUE              MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1               10    1  90266  10069     4.826     0.002      0.002    0

STORAGE            CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL                2    0    0    2    90266    1   1.866  0.933    0     0

TABLE              MEAN     STD.DEV.      RANGE           RETRY FREQUENCY CUM.%
 T_W               0.002    0.001                           0
                                      _  -      0.000              19250    21.33
                                  0.000  -      0.001               9868    32.26
                                  0.001  -      0.001              10215    43.58
                                  0.001  -      0.002              10616    55.34
                                  0.002  -      0.002              10424    66.88
                                  0.002  -      0.002               9052    76.91
                                  0.002  -      0.003               7398    85.11
                                  0.003  -      0.003               5324    91.01
                                  0.003  -      0.004               3461    94.84
                                  0.004  -  _                       4657   100.00
 T_U               0.002    0.001                           0
                                      _  -      0.001              14294    17.58
                                  0.001  -      0.002              17199    38.73
                                  0.002  -      0.002              18110    61.00
                                  0.002  -      0.003              15313    79.83
                                  0.003  -      0.004               9382    91.37
                                  0.004  -      0.005               4420    96.81
                                  0.005  -      0.006               1704    98.90
                                  0.006  -      0.006                629    99.68
                                  0.006  -      0.007                206    99.93
                                  0.007  -                            57   100.00
```

Figure A.1 – Fragment of the report for the model with $N = 2$

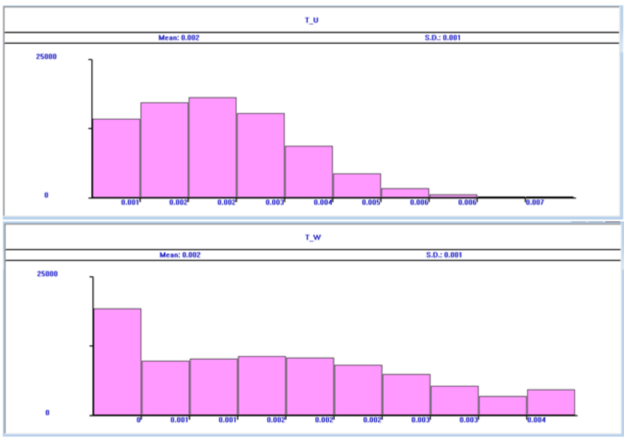


Figure A.2 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_W$ of requests $N = 2$

```
QUEUE              MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1               10    1  99605  53200     0.951     0.000      0.001    0

STORAGE            CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL                3    0    0    3    99605    1   2.047  0.682    0     0

TABLE              MEAN     STD.DEV.      RANGE           RETRY FREQUENCY CUM.%
 T_W               0.000    0.000                           0
                                      _  -      0.000              75800    76.10
                                  0.000  -      0.001              11400    87.55
                                  0.001  -      0.001               6100    93.67
                                  0.001  -      0.002               3356    97.04
                                  0.002  -      0.002               1679    98.73
                                  0.002  -      0.002                809    99.54
                                  0.002  -      0.003                285    99.82
                                  0.003  -      0.003                109    99.93
                                  0.003  -      0.004                 46    99.98
                                  0.004  -  _                         20   100.00
 T_U               0.001    0.001                           0
                                      _  -      0.001              51706    57.64
                                  0.001  -      0.002              24423    84.87
                                  0.002  -      0.002               9341    95.28
                                  0.002  -      0.003               3045    98.68
                                  0.003  -      0.004                828    99.60
                                  0.004  -      0.005                272    99.90
                                  0.005  -      0.006                 68    99.98
                                  0.006  -      0.006                 17   100.00
                                  0.006  -      0.007                  3   100.00
```

Figure A.3 – Fragment of the report for the model with $N = 3$

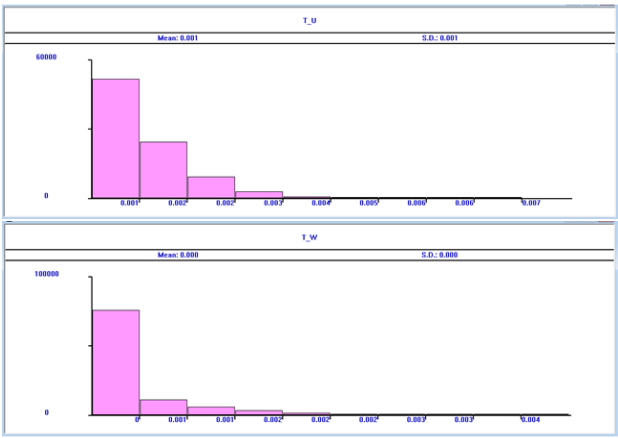


Figure A.4 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_W$ of requests $N = 3$

```
QUEUE              MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1               10    0  99989  81309     0.200     0.000      0.000    0

STORAGE            CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL                4    3    0    4    99989    1   2.056  0.514    0     0

TABLE              MEAN     STD.DEV.      RANGE           RETRY FREQUENCY CUM.%
 T_W               0.000    0.000                           0
                                      _  -      0.000              94942    94.95
                                  0.000  -      0.001               3638    98.59
                                  0.001  -      0.001               1052    99.64
                                  0.001  -      0.002                258    99.90
                                  0.002  -      0.002                 80    99.98
                                  0.002  -      0.002                 16   100.00
                                  0.002  -      0.003                  3   100.00
 T_U               0.001    0.001                           0
                                      _  -      0.001              63515    70.46
                                  0.001  -      0.002              19535    92.13
                                  0.002  -      0.002               5254    97.96
                                  0.002  -      0.003               1343    99.45
                                  0.003  -      0.004                366    99.85
                                  0.004  -      0.005                106    99.97
                                  0.005  -      0.006                 25   100.00
                                  0.006  -      0.006                  1   100.00
                                  0.006  -      0.007                  1   100.00
```

Figure A.5 – Fragment of the report for the model with $N = 4$


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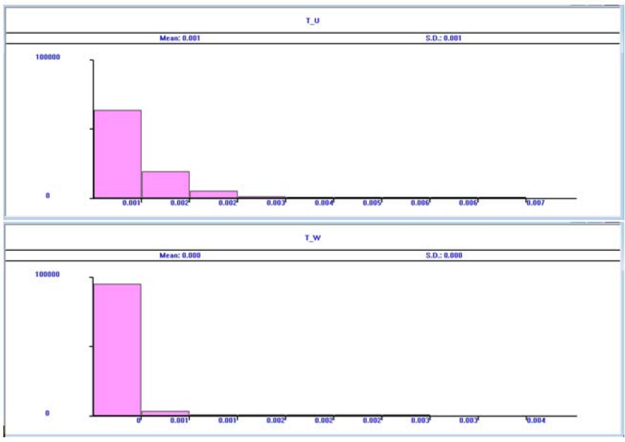


Figure A.6 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_W$ of requests $N = 4$

```
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
```

Figure A.7 – Fragment of the report for the model with $N = 5$

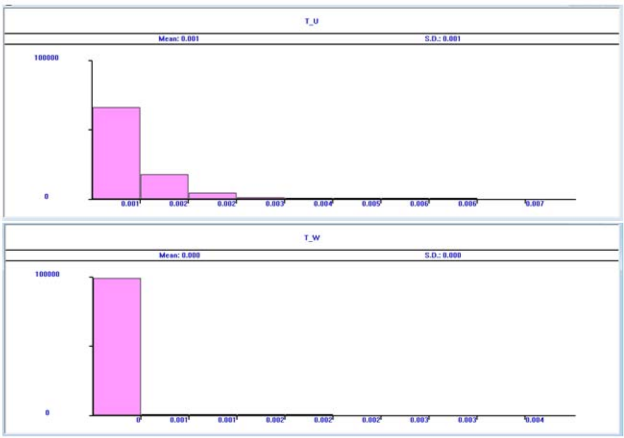


Figure A.8 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_W$ of requests $N = 5$

**Appendix B**

Results of the second case's simulation model of the ISS's operation.

```
QUEUE          MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1          10    10  93922   5263     5.047     0.002      0.002    0

STORAGE        CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL           2    0    0    2    93912    1    1.932  0.966    0    10

TABLE          MEAN     STD.DEV.        RANGE            RETRY FREQUENCY CUM.%
 T_W           0.002     0.001                             0
                                  _  -       0.000                 13253    14.11
                              0.000  -       0.001                 10024    24.79
                              0.001  -       0.001                 11128    36.64
                              0.001  -       0.002                 12288    49.72
                              0.002  -       0.002                 13158    63.73
                              0.002  -       0.002                 13948    78.58
                              0.002  -       0.003                 14840    94.39
                              0.003  -       0.003                  5273   100.00
 T_U           0.002     0.001                             0
                                  _  -       0.001                  8029     9.49
                              0.001  -       0.002                 18103    30.90
                              0.002  -       0.002                 22165    57.11
                              0.002  -       0.003                 25273    86.99
                              0.003  -       0.004                 11004   100.00
```

Figure B.1 – Fragment of the report for the model with $N = 2$

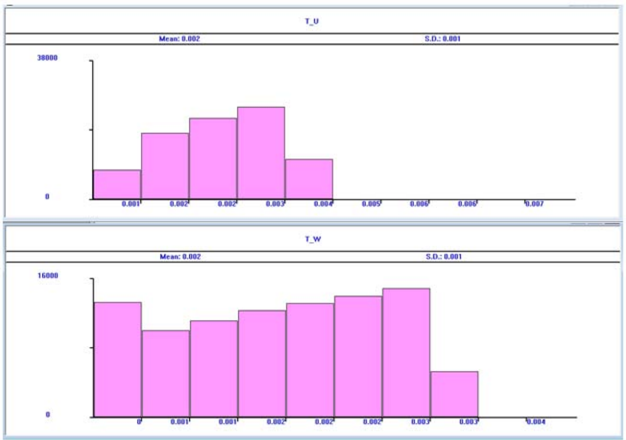


Figure B.2 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_W$ of requests $N = 2$

```
QUEUE          MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1          10     0  99980  54126     0.549     0.000      0.000    0

STORAGE        CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL           3    2    0    3    99980    1    2.061  0.687    0     0

TABLE          MEAN     STD.DEV.        RANGE            RETRY FREQUENCY CUM.%
 T_W           0.000     0.000                             0
                                  _  -       0.000                 85307    85.32
                              0.000  -       0.001                 11147    96.47
                              0.001  -       0.001                  2716    99.19
                              0.001  -       0.002                   659    99.85
                              0.002  -       0.002                   144    99.99
                              0.002  -       0.002                     7   100.00
 T_U           0.001     0.000                             0
                                  _  -       0.001                 65090    72.35
                              0.001  -       0.002                 23406    98.37
                              0.002  -       0.002                  1438    99.96
                              0.002  -       0.003                    32   100.00
```

Figure B.3 – Fragment of the report for the model with $N = 3$

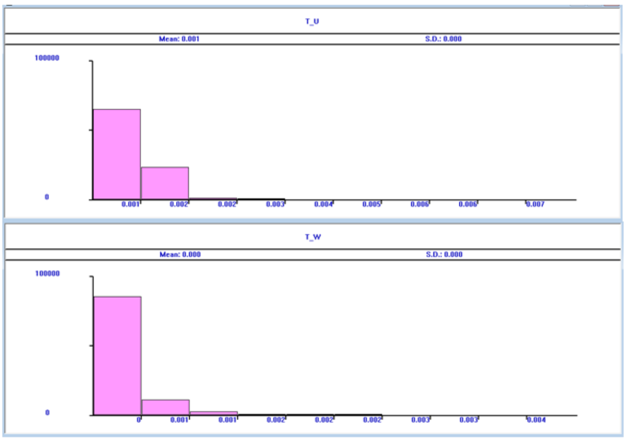


Figure B.4 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_W$ of requests $N = 3$

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```
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
```

Figure B.5 – Fragment of the report for the model with $N = 4$

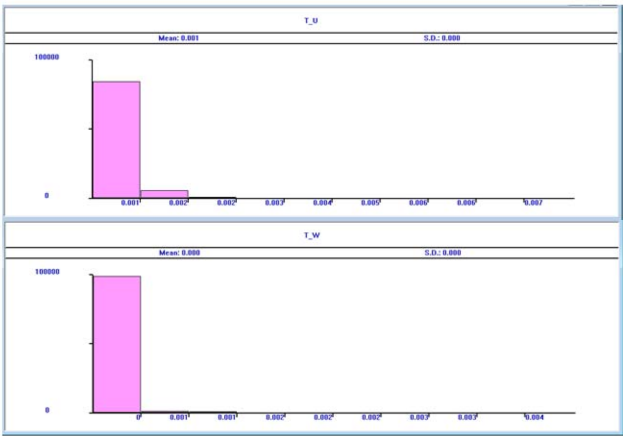


Figure B.6 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_W$ of requests $N = 4$

```
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
```

Figure B.7 – Fragment of the report for the model with $N = 5$

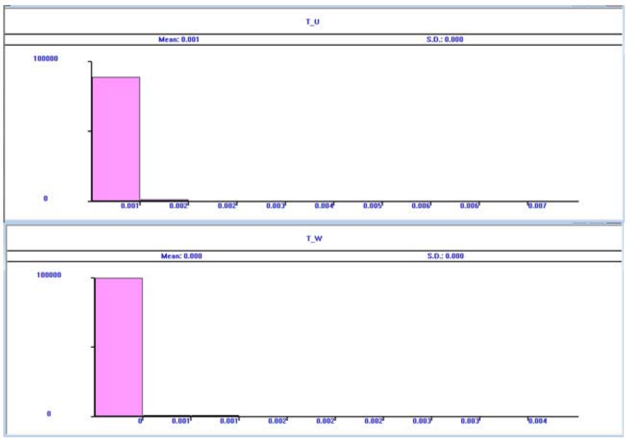


Figure B.8 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_W$ of requests $N = 5$

**Appendix C**

Results of the third case's simulation model of the ISS's operation.

```
QUEUE            MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1             10    6  91907   7758     4.921     0.002      0.002    0

STORAGE          CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL              2    0    0    2    91902   1    1.898  0.949    0    5

TABLE            MEAN     STD.DEV.        RANGE            RETRY FREQUENCY CUM.%
 T_W             0.002     0.001                                 0
                                          -      0.000             16613    18.08
                                 0.000    -      0.001             10031    28.99
                                 0.001    -      0.001             11184    41.16
                                 0.001    -      0.002             11418    53.59
                                 0.002    -      0.002             11645    66.26
                                 0.002    -      0.002             10743    77.95
                                 0.002    -      0.003              8832    87.56
                                 0.003    -      0.003              5696    93.76
                                 0.003    -      0.004              3276    97.32
                                 0.004    -  _                      2463   100.00
 T_U             0.002     0.001                                 0
                                          -      0.001             11476    13.84
                                 0.001    -      0.002             18300    35.92
                                 0.002    -      0.002             20131    60.20
                                 0.002    -      0.003             18139    82.08
                                 0.003    -      0.004             10430    94.66
                                 0.004    -      0.005              3405    98.76
                                 0.005    -      0.006               851    99.79
                                 0.006    -      0.006               161    99.98
                                 0.006    -      0.007                13   100.00
```

Figure C.1 – Fragment of the report for the model with $N = 2$

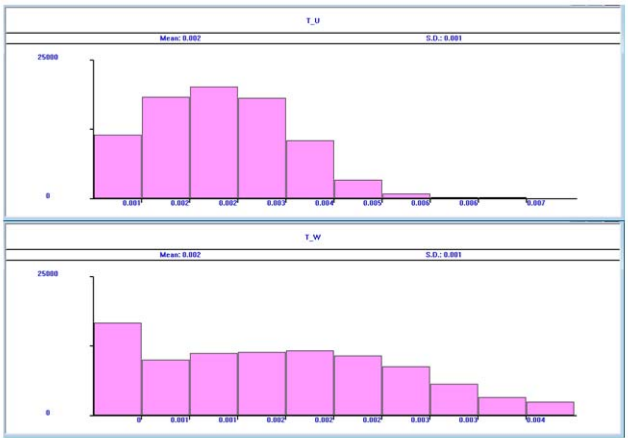


Figure C.2 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_W$ of requests $N = 2$

```
QUEUE            MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1             10    0  99833  53152     0.786     0.000      0.000    0

STORAGE          CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL              3    1    0    3    99833   1    2.053  0.684    0    0

TABLE            MEAN     STD.DEV.        RANGE            RETRY FREQUENCY CUM.%
 T_W             0.000     0.000                                 0
                                          -      0.000             78532    78.66
                                 0.000    -      0.001             12483    91.17
                                 0.001    -      0.001              5268    96.44
                                 0.001    -      0.002              2232    98.68
                                 0.002    -      0.002               932    99.61
                                 0.002    -      0.002               284    99.90
                                 0.002    -      0.003                81    99.98
                                 0.003    -      0.003                14    99.99
                                 0.003    -      0.004                 7   100.00
 T_U             0.001     0.001                                 0
                                          -      0.001             52246    58.16
                                 0.001    -      0.002             28786    90.21
                                 0.002    -      0.002              7193    98.21
                                 0.002    -      0.003              1388    99.76
                                 0.003    -      0.004               187    99.97
                                 0.004    -      0.005                26   100.00
                                 0.005    -      0.006                 4   100.00
```

Figure C.3 – Fragment of the report for the model with $N = 3$

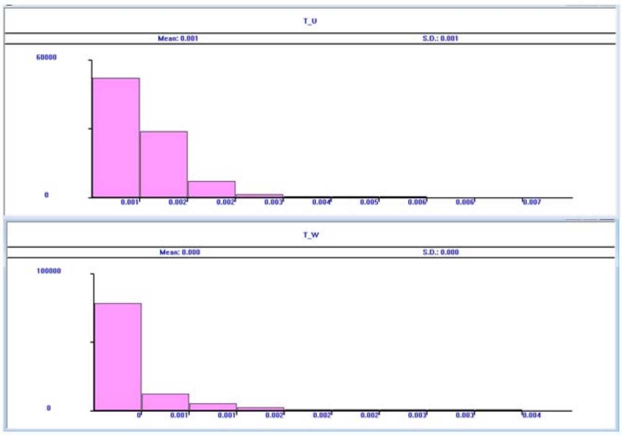


Figure C.4 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_\mathrm{W}$ of requests $N=3$

```
QUEUE              MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1               10     3 100003  81249     0.166     0.000      0.000    0

STORAGE            CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL                4    0    0    4   100001   1    2.061  0.515    0     2

TABLE              MEAN     STD.DEV.       RANGE             RETRY FREQUENCY CUM.%
 T_W               0.000     0.000                              0
                                          -       0.000                96173    96.17
                                  0.000   -       0.001                 3194    99.37
                                  0.001   -       0.001                  509    99.88
                                  0.001   -       0.002                   91    99.97
                                  0.002   -       0.002                   26    99.99
                                  0.002   -       0.002                    7   100.00
 T_U               0.001     0.000                              0
                                          -       0.001                64240    71.40
                                  0.001   -       0.002                22423    96.33
                                  0.002   -       0.002                 2962    99.62
                                  0.002   -       0.003                  308    99.96
                                  0.003   -       0.004                   32   100.00
                                  0.004   -       0.005                    2   100.00
```

Figure C.5 – Fragment of the report for the model with $N = 4$

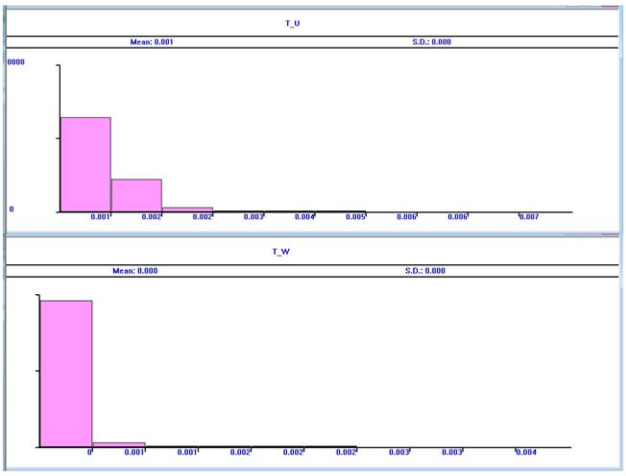


Figure C.6 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_\mathrm{W}$ of requests $N=4$

```
QUEUE              MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 CH_1               10     0 100002  93516     0.040     0.000      0.000    0

STORAGE            CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 UZEL                5    3    0    5   100002   1    2.058  0.412    0     0

TABLE              MEAN     STD.DEV.       RANGE             RETRY FREQUENCY CUM.%
 T_W               0.000     0.000                              0
                                          -       0.000                99406    99.40
                                  0.000   -       0.001                  535    99.94
                                  0.001   -       0.001                   54    99.99
                                  0.001   -       0.002                    7   100.00
 T_U               0.001     0.000                              0
                                          -       0.001                67088    74.46
                                  0.001   -       0.002                20334    97.03
                                  0.002   -       0.002                 2419    99.71
                                  0.002   -       0.003                  239    99.98
                                  0.003   -       0.004                   18   100.00
                                  0.004   -       0.005                    1   100.00
```

Figure C.7 – Fragment of the report for the model with $N = 5$

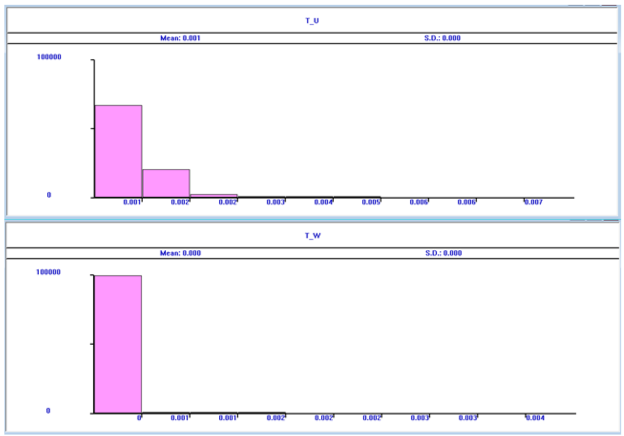


Figure C.8 – Histograms of the probability density functions of the residence time $T\_U$ and waiting time $T\_\mathrm{W}$ of requests $N=5$

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## АНАЛІЗ РЕЗУЛЬТАТІВ ІМІТАЦІЙНОГО МОДЕЛЮВАННЯ СИСТЕМИ БЕЗПЕКИ ІНФОРМАЦІЇ ВІД НЕСАНКЦІОНОВАНОГО ДОСТУПУ У МЕРЕЖАХ ОБСЛУГОВУВАННЯ

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### АНОТАЦІЯ

**Актуальність.** Аналіз мережі обслуговування показує, що недостатня захищеність інформації в мережах обслуговування є причиною великих збитків, завданих корпораціями. Незважаючи на появу низки робіт, та матеріалів зі стандартизації, в даний час єдина система оцінки захищеності інформації в галузі інформаційної безпеки відсутня. Слід зазначити, що існуючі методи, і навіть накопичений досвід у цій галузі неможливо повністю подолати ці труднощі. Ця обставина **підтверджує**, що дана проблема ще недостатньо вивчена і, отже, зберігає свою актуальність. Представлена робота є одним із кроків на шляху створення єдиної системи оцінки безпеки інформації у мережах обслуговування.

**Мета роботи.** Розробка алгоритму та моделі імітації, аналіз результатів моделі імітації для визначення основних характеристик системи безпеки інформації, що надають можливість повного закриття, за допомогою системи безпеки, всіх можливих каналів прояву загроз, шляхом забезпечення контролю переходу всіх запитів несанкціонованого доступу через механізм захисту.

**Метод.** Для вирішення поставленого завдання було застосовано метод імітаційного моделювання з використанням принципів моделювання системи масового обслуговування. Даний метод дозволяють отримати основні характеристики системи безпеки інформації від несанкціонованого доступу з обмеженим обсягом буферної пам'яті.

**Результати.** Розроблено новий алгоритм, моделі та методологію розробки системи безпеки інформації від несанкціонованого доступу, що розглядається як однофазна багатоканальна системи масового обслуговування з обмеженим обсягом буферної пам'яті. Процес одержання результатів моделі було реалізовано системі моделювання General Purpose Simulation System World і проведено порівняльні оцінки основних характеристик системи безпеки інформації щодо різних законів розподілу вихідних параметрів, тобто. при цьому запити несанкціонованого доступу є найпростішими потоками, а час обслуговування підпорядковується експоненційному, постійному та законам Ерлангового розподілу.

**Висновки.** Проведені експерименти на основі алгоритму та моделі підтвердили очікувані результати при аналізі характеристик системи безпеки інформації від несанкціонованого доступу як однофазної багатоканальної системи масового обслуговування з обмеженим часом очікування запитів у черзі. Ці результати можуть бути використані для практичної побудови нових або модифікації існуючих системи безпеки інформації в мережах обслуговування об'єктів різного призначення. Дана робота є одним з підходів до узагальнення розглянутих проблем для систем з обмеженим обсягом буферної пам'яті. Перспективи подальших досліджень включають в себе дослідження та розробку принципів апаратно-програмної реалізації системи безпеки інформації в мережах обслуговування.

**КЛЮЧОВІ СЛОВА:** несанкціонований доступ, системи безпеки інформації, інформаційна безпека, системи масового обслуговування, механізм захисту, імітаційна моделювання.


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**ЛІТЕРАТУРА**

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