Збірник наукових праць ДНУЗТ ім. акад. В. Лазаряна. Вип. 19. 2020 р.

UDC 656.135.073

N. O. LUZHANSKA[1]*

[1*] Department of Transport Technologies, National Transport University, Omelianovycha-Pavlenka str. 1, Kyiv, 01010, Ukraine, tel. +38 (068) 811-61-21, e-mail: natali.luzhanska@gmail.com, ORCID –ID 0000-0002-1271-8728

SIMULATION AND OPTIMIZATION OF FREIGHT CUSTOMS COMPLEXES` BASED ON QUEUEING SYSTEMS

Abstract. The **purpose** of the article is to create a simulation model for the study and optimization of a freight customs complex`s structure when performing export and import operations, comprehensive service provision, and the stowage of goods in a customs warehouse or a temporary storage warehouse. **Methodology** is the simulation modeling of queuing systems. The mathematical model of the freight customs complex (FCC) is presented as a queuing system. The simulation model of the freight customs complex has been developed in the GPSS World simulation automation package. The simulation model was tested including two stages –verification and validity check. Studying the properties of the model, simulation accuracy was estimated; the length of the simulation transition period was determined; the stability of simulation model responses was evaluated; the sensitivity of model responses to changes in the number of vehicles requiring service was determined. **Findings**. Based on the developed simulation model, it was conducted the study on customs and logistics service operations provided for freight owners in the export and import of goods, comprehensive servicing, and freight storage in a customs warehouse and a temporary storage warehouse. The simulation model validation results at one of freight customs complexes in the Kyiv region are presented. **Originality** consists in the opportunity to research the processes at freight customs complexes using simulation modeling with the different degrees of detail and over time optimizing its structure. **Practical value**. The developed simulation model of the freight customs complex provides an opportunity to identify the average time spent by vehicles on the territory of the freight customs complex when performing export and import operations, comprehensive service provision, and the stowage of goods in a customs warehouse and a temporary storage warehouse; the probability of service refusal due to the lack of parking spaces for vehicles in the customs control zone; the optimal number of customs inspectors and vehicle parking spaces; the optimal sizes of warehouse space for placing freight in a customs warehouse or a temporary storage warehouse. This will make it possible not only to analyze the operation of the freight customs complex but also to optimize its structure, to determine measures that will increase the throughput capacity of the freight customs complex.

Keywords: freight customs complex; simulation modeling; queuing systems

Introduction

For foreign economic activity realization, freight customs complexes with customs warehouses, temporary storage warehouses in their structure performing freight forwarding, customs and brokerage as well as other functions are the most demanded.

Freight customs complexes located throughout the country have a different level of technical, technological and organizational support, as well as different throughput capacity restricted by the availability of personnel and free space for access to their territory or facilities to store goods in the required volumes and for certain periods

An important aspect when choosing a freight customs complex as a business entity is the presence of service queues or the likelihood of service refusal. Therefore, the urgent task is to study and optimize the structure of a freight customs complex when performing export and import operations, comprehensive service provision, and the stowage of goods in a customs warehouse or a temporary storage warehouse.

Structurally, customs and logistics vehicle service operations at a freight customs complex can be represented as a multiphase queuing system

Due to the complex organization of interaction between the elements of a freight customs complex, the likelihood of vehicle service and freight storage refusal in a customs warehouse or a temporary storage warehouse, individual employees` working hours and shift, as well as various distribution laws of arrival time and the servicing of traffic flows, the analytical study of a queuing mathematical model of a freight customs complex is not applicable or has complex calculation algorithms taking into account a large number of indicators.

For this reason, the most effective research and optimization method of a freight customs complex`s operation is simulation [1, 2]. And the use of GPSS simulation system will automate its modeling process and carrying out a simulation experiment and

doi: https://doi.org/10.15802/tstt2020/208693

will allow the performance description of individual system components with the necessary degree of detail, the investigation of customs and logistics service processes in dynamics with changing system parameters over time [2, 3, 4].

Analysis of literary sources and research objectives

Nowadays, there are many different methodologies, as well as a wide range of specialized software packages designed for the simulation of logistics supply chains and customs infrastructure facilities [5-14].

The list of specialized packages is constantly expanding, but most of them are quite expensive and require specialists` retraining. For this reason, the works [5, 7, 11] are devoted to the development of proprietary software systems.

For supply chain simulation the paper [5] uses a relatively new system modeling language, OMG SysML™, because it provides a rich set of fundamental abstractions, leads to models on which computations are easily performed, and provides a set of mechanisms for customizing the language for a particular domain.

So, for example, in [11] for the study of the customs control system, a specialized simulation system was proposed based on the aggregate modeling method.

Many modern publications focus on the development of logistics transport and customs infrastructure simulation models in the AnyLogic system [13], with fairly extensive functionality. For example, in [9], it is developed an agent-based system dynamics simulation model to achieve a stable state of the main parameters of intermodal terminals.

The purpose of the paper is the development of a freight customs complex simulation model, which will not only optimize its structure, but also increase throughput capacity when performing export and import operations, comprehensive service provision, and the stowage of goods in a customs warehouse or a temporary storage warehouse.

Research methodology

A simulation model of a freight customs complex. To substantiate the possibility of a freight customs complex optimization, the queuing mathematical model is proposed.

Vehicles arrive at a freight customs complex to carry out customs and logistics service operations: export and import customs clearance, comprehensive service, the stowage of goods in a customs warehouse and a temporary storage warehouse [14].

A graphical representation of the movement of traffic flows going through export custom clearance formalities using the services of a freight customs complex is shown in Figure 1.

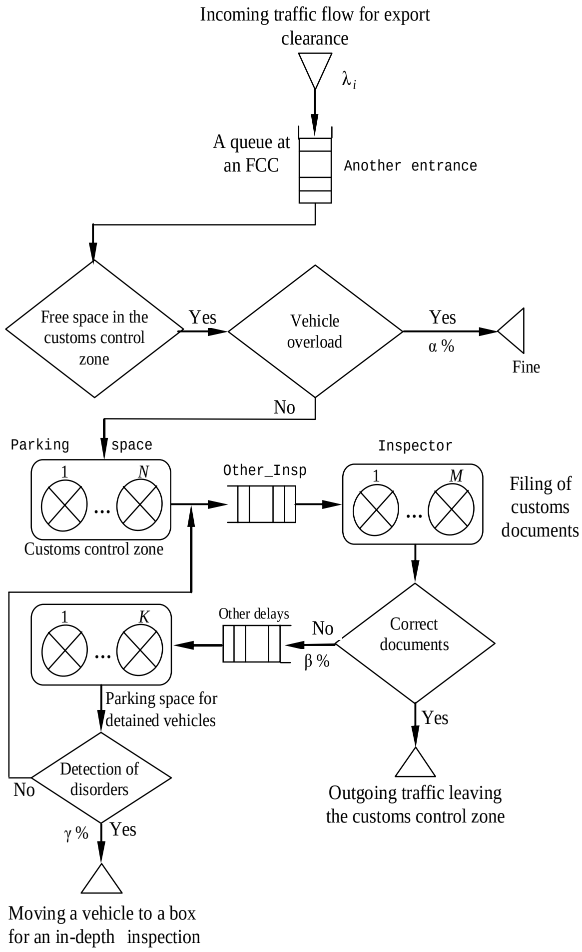


Fig. 1. Conceptual model of freight export operations

Time intervals between the arrivals of vehicles (service requests) for the export of goods have a Poisson distribution with λ_i. intensity. Arriving vehicles are waiting in a queue for service until they obtain permission to enter the territory of a freight customs complex. If there is free space and given a successful weight-checking procedure (α % of vehicles get a refusal to be serviced due to overload), vehicles enter the customs control zone with *N* parking lots. When filing customs documents, applications are waiting to be processed. There are *M* customs inspectors (servers) working on the territory of the freight customs complex. The service time of one vehicle by an inspector is determined according to the Gaussian law with the mean value m_i and the standard deviation σ_i. With the correct execution of documents, an outgoing traffic flow from the customs control zone is formed. β % of vehicles move to the parking for detained cars with *K* parking spaces. If violations are detected, γ % of the vehicles is moved to a box for an in-depth inspection. The rest of the cars after document amendments form an outgoing traffic flow from the customs control zone.

The mathematical models of freight import operations, comprehensive service provision, and the stowage of goods in a customs warehouse or a temporary storage warehouse are of a similar structure.

As criteria used to determine the optimal structure of the freight customs complex, the following are considered: average queuing time; maximum and average lengths of queues for service; server load factors; average time vehicles spent on the territory of a freight customs complex.

The controlled variables (parameters) of the simulation are the intensity of vehicles arriving at a freight customs complex for the provision of customs and logistics services

The simulation model restrictions are related to the conditions imposed on the flow of incoming vehicles (it is assumed to be the simplest, there are no repeated applications); the absence of phenomena changing the patterns of vehicle service time at the freight customs complex (equipment failures and malfunctions, etc.).

The proposed queuing model of the freight customs complex is developed in the GPSS World simulation automation package [2, 3].

The properties of the simulation model of the freight customs complex have been tested and studied.

The simulation model test included two stages: verification and validity check. At the verification stage, the correctness of the operating algorithm of the freight customs complex simulation model using the model's interactive single-step debugging properties was checked. It allows setting breakpoints in the model and gives theopportunity to determine the parameters of its service requests. Using verification, the logical structure of the model has been identified as correct.

Verification carried out during the complex debugging of the program on real initial data showed that the developed simulation model of the freight customs complex in all situations corresponds to the operation of the object under study.

The model validity was verified by matching the values of the model functioning characteristics with the data obtained by analytical calculations to the specified accuracy.

In the study of the properties of the freight customs complex simulation model, the simulation accuracy was evaluated, the length of the simulation transition period was determined; the stability of simulation model responses was evaluated; the sensitivity of model responses was identified. Determining the sensitivity of model responses, it was necessary to evaluate the percentage of changes in model responses depending on the number of vehicles requiring service.

In the process of collecting simulation statistics, the data such as average queue lengths (η_k), average queuing time (w_k), and server load factors (ψ_k) are determined. Then, for each server, the value of the time loss of vehicle service requests in queues is calculated:

$$LT_k = \eta_k \cdot w_k \quad (1)$$

For the obtained values, the diagrams of the relationship between server load intensity and the time loss of vehicles in queues are constructed.

Servers with a maximum value of a simulation statistics pair (LT_k; ψ_k) are considered the bottlenecks of the freight customs complex.

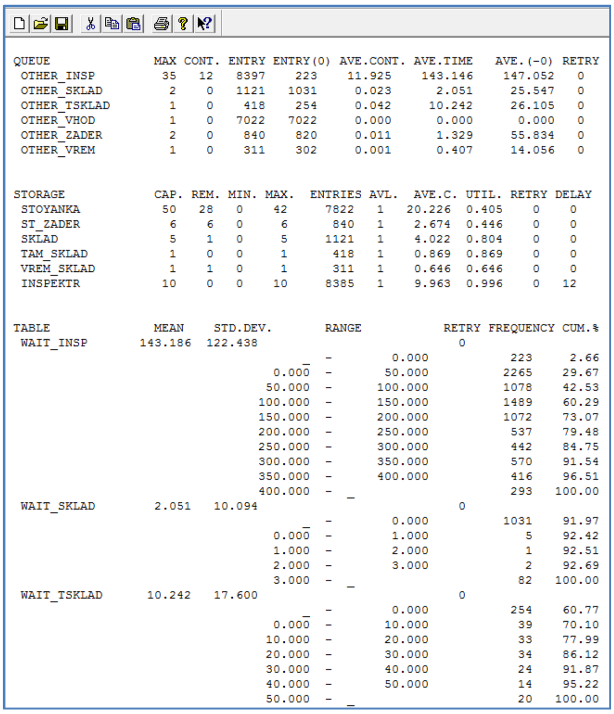
Devices that have maximum LT_k values and minimum ψ_k values are considered the unbalanced operation points of the freight customs complex.

Analyzing the above diagrams, the optimal structure of the freight customs complex is selected.

Freight customs complex simulation model testing

The simulation model was tested at one of freight customs complexes in the Kyiv region.

Based on the reports obtained as a result of freight customs complex modeling (Figure 2), the main indicators of the modeling results were determined and the time loss value of vehicle service requests in queues was calculated (Table 1).



```
QUEUE              MAX CONT. ENTRY ENTRY(0) AVE.CONT. AVE.TIME   AVE.(-0) RETRY
 OTHER_INSP         35   12   8397    223    11.925   143.146    147.052   0
 OTHER_SKLAD         2    0   1121   1031     0.023     2.051     25.547   0
 OTHER_TSKLAD        1    0    418    254     0.042    10.242     26.105   0
 OTHER_VHOD          1    0   7022   7022     0.000     0.000      0.000   0
 OTHER_ZADER         2    0    840    820     0.011     1.329     55.834   0
 OTHER_VREM          1    0    311    302     0.001     0.407     14.056   0

STORAGE            CAP. REM. MIN. MAX.  ENTRIES AVL.  AVE.C. UTIL. RETRY DELAY
 STOYANKA           50   28    0   42     7822   1   20.226 0.405    0     0
 ST_ZADER            6    6    0    6      840   1    2.674 0.446    0     0
 SKLAD               5    1    0    5     1121   1    4.022 0.804    0     0
 TAM_SKLAD           1    0    0    1      418   1    0.869 0.869    0     0
 VREM_SKLAD          1    1    0    1      311   1    0.646 0.646    0     0
 INSPEKTR           10    0    0   10     8385   1    9.963 0.996    0    12

TABLE              MEAN    STD.DEV.       RANGE           RETRY FREQUENCY CUM.%
 WAIT_INSP       143.186  122.438                           0
                                     _  -       0.000                223    2.66
                                 0.000  -      50.000               2265   29.67
                                50.000  -     100.000               1078   42.53
                               100.000  -     150.000               1489   60.29
                               150.000  -     200.000               1072   73.07
                               200.000  -     250.000                537   79.48
                               250.000  -     300.000                442   84.75
                               300.000  -     350.000                570   91.54
                               350.000  -     400.000                416   96.51
                               400.000  -  _                         293  100.00
 WAIT_SKLAD        2.051   10.094                           0
                                     _  -       0.000               1031   91.97
                                 0.000  -       1.000                  5   92.42
                                 1.000  -       2.000                  1   92.51
                                 2.000  -       3.000                  2   92.69
                                 3.000  -  _                          82  100.00
 WAIT_TSKLAD      10.242   17.600                           0
                                     _  -       0.000                254   60.77
                                 0.000  -      10.000                 39   70.10
                                10.000  -      20.000                 33   77.99
                                20.000  -      30.000                 34   86.12
                                30.000  -      40.000                 24   91.87
                                40.000  -      50.000                 14   95.22
                                50.000  -  _                          20  100.00
```

Fig. 2. Simulation Results in GPSS

Table 1

Freight customs complex modeling results

	Inspector PR_1	Parking in the customs control zone PR_2	Parking for detained vehicles PR_3	Comprehensive service warehouse PR_4	Customs warehouse PR_5	Temporary storage warehouse PR_6
Load factor ψ_k	0.996	0.405	0.446	0.804	0.869	0.646
Average queuing time, min	143	0	1,33	2,051	10,24	0,407
Average queue length, vehicles η_k	12	0	0,11	0,023	0,042	0,01
Vehicles served without queuing time, % w_k	2,7 %	100 %	98 %	91 %	60 %	97 %
LT_k	1716	0	0,15	0,05	0,43	0,04

According to the simulation results, the average time vehicles spend at the freight customs complex for customs and logistics service provision will be the following:

– export customs clearance –263 ± 30 min, if the paperwork is incorrect –648± 30 min;

– import customs clearance – 263 ± 30 min, if the paperwork is incorrect –648± 30 min;

– comprehensive service –494±120 min,

– stowage of goods in a customs warehouse – 504±120 min;

– stowage of goods in a temporary storage warehouse –474±120 min.

The histogram (Figure 3) shows the distribution of the queuing time for a vehicle to be serviced by an inspector. Thus, the average queuing time is 143.186 minutes, the standard deviation is 122.428 minutes.

The distribution of queuing time for the freight stowage at the customs warehouse is shown in Figure 4. The average waiting time is 10.2 minutes; the standard deviation is 17.6 minutes.

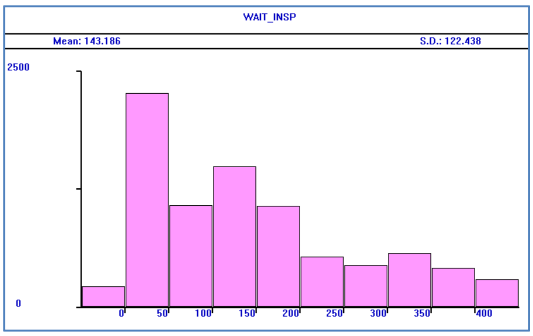


Fig. 3 Distribution of the queuing time for a vehicle to be serviced by an inspector

Figure 5 shows a diagram of the relationship between the server load intensity and the time loss of vehicle service requests (LT_k).

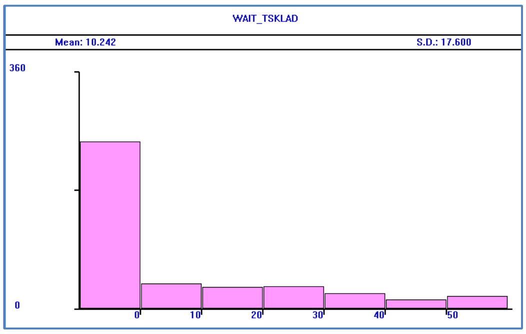


Fig. 4 Distribution of the queuing time for freight stowage at the customs warehouse

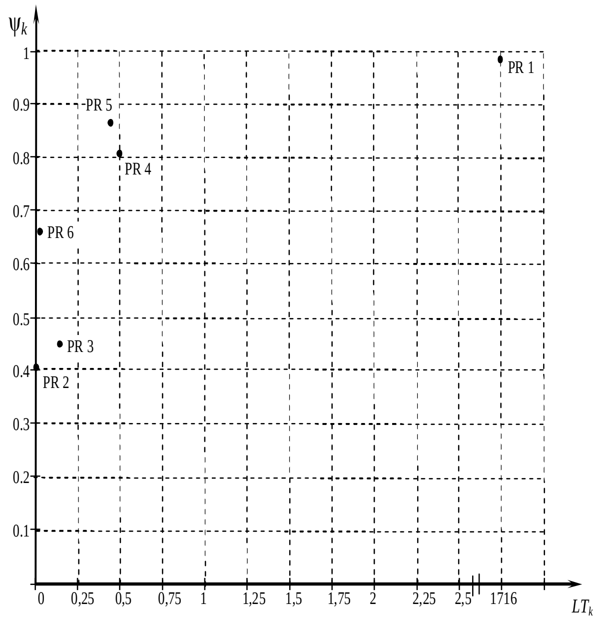


Fig. 5 Diagram of the relationship between server load intensity and the time loss of vehicle service requests

Analyzing the obtained simulation results and the relationship diagram, we can conclude that the “bottleneck” for this freight customs complex is the number of inspectors, an increase in their quantity will enhance the throughput capacity and reduce the vehicle service time to execute all customs and logistics service operations. However, the number of parking spaces for vehicles in the customs control zone, in the parking for detained cars, the area of the comprehensive service warehouse, the customs warehouse, andthe temporary storage warehouse are sufficient.

Conclusions

The proposed simulation model of the freight customs complex makes it possible to determine:

– throughput capacity of a freight customs complex;

– average time spent by vehicles on the territory of the freight customs complex, including queuing time;

– queuing time for a vehicle to obtain permission to enter the territory of the customs infrastructure facility;

– probability of service refusal due to the limitation on the number of vehicles that can simultaneously be found on the territory of the freight customs complex;

– optimal number of parking spaces for vehicles in the customs control zoneand in the parking for detained cars;

– optimal number of customs inspectors working on the territory of the freight customs complex (taking into account the individual duration of their working day and shifts);

– likelihood of a refusal to store cargo in a customs warehouse or temporary storage warehouse, provided that there is no free storage space;

– optimal size of the storage space for storing goods in a customs warehouse or a temporary storage warehouse so that the refusal probability does not exceed a particular value;

– optimal service time values for various combinations of the intensity of arriving vehicles, in order to increase the throughput capacity of the freight customs complex.

Thus, the developed simulation model will make it possible to analyze and to improve the operating modes of the freight customs complex.

REFERENCES

1. Taha, Hamdy A. Operations research: an introduction [Text] / Hamdy A. Taha – New Jersey: Upper Saddle River, 2007. – 815 p.

2. Shevchenko, D. N. Imitacionnoe modelirovanie na GPSS: ucheb.-metod. posobie dlja studentov tehnicheskih special'nostej [Tekst]/ D. N. Shevchenko, I. N. Kravchenja. – Gomel': BelGUT, 2007. – 97 s.

3. GPSS World Reference Manual [Text] / Minuteman Software. – Holly Springs NC, 2001. – p. 305.

4. Kravchenya I. Simulation modeling in GPSS for optimizing the traffic lights cycle of adjustable crossroads [Text] / I. Kravchenya, I. Lebid // Journal of Sustainable Development of Transport and Logistics – 2020. – Iss.5(1) – p. 48-55. doi:10.14254/jsdtl.2020.5-1.5

5. Thiers G., Logistics systems modeling and simulation [Text] / G. Thiers, L. McGinnis // Proceedings of the 2011Winter Simulation Conference. – 2011. – p. 1536-1546.

6. Yang-Byung P. Simulation-Based Evolutionary Algorithm Approach for Deriving the Operational Planning of Global Supply Chains from the Systematic Risk Management [Text] / P. Yang-Byung, K. Hyung-Seok // Computers in Industry – 2016. – Iss. 83. – p. 68-77. doi.org/10.1016/j.compind.2016.09.003

7. Fanti M. P. Simulation Based Decision Support System for Logistics Management [Text] / M. P. Fanti, G. Iacobellis, W. Ukovich, V.Boschian, C. Stylios // Journal of Computational Science. – 2015. – Iss. 10. – p. 86-96. doi.org/10.1016/j.jocs.2014.10.003

8.Kotachi M. Simulation Modeling and Analysis of Complex Port Operations with Multimodal Transportation [Text] / M. Kotachi, G. Rabadi, M. Obeid // Procedia Computer Science. – 2013. – Iss. 20. – P. 229-234. doi.org/10.1016/j.procs.2013.09.266

9. MuravevD.Multi-Agent Optimization of the Intermodal Terminal Main Parameters by Using AnyLogicSimulation Platform: Case study on the Ningbo-Zhoushan Port [Text] / D. Muravev, H. Hu, A.Rakhmangulov, P.Mishkurov // International Journal of Information Management. – 2020. –Article 102133.doi.org/10.1016/j.ijinfomgt.2020.102133

10. Martagan T. G. A Simulation Model of Port Operations During Crisis Conditions [Text]/ T.G. Martagan, B. Eksioglu, S. D. Eksioglu., A. G. Greenwood // Proceedings of the 2009 Winter Simulation Conference. – 2009. – p. 2832- 2843.

11. Lipatova N.G. Imitacionnoe modelirovanie processov tamozhennogokontrolja [Tekst]: monografija / N. G. Lipatova. – M.: Izd-vo Rossijskotamozhennojakademii, 2015. – 164 s.

12. Nigmatulin T. A. Optimizacijakompleksatehnicheskihsredstvtamozhen-nogokontroljametodomimitacionnogo modelirovanija [Tekst] / T. A.Nigmatulin , T. A. Ulitova // Uchenye zapiski Sankt-Peterburgskogo imeni V.B. Bobkova filiala rossijskoj tamozhennoj akademii.– 2016. – 2(58). – s. 14-18

13. AnyLogic. Mnogopodhodnoe imitacionnoe modelirovanie [Tekst] – [Elektronnyj resurs]. – Rezhim dostupa: http://www.anylogic.ru

14. Luzhanska N. The influence of customs and logistics service efficiency on cargo delivery time [Text] / N.Luzhanska, I.Lebid, O.Kotsiuk, I.Kravchenya, Y.Demchenko // Proceedings of the National Aviation University. – 2019. – Vol. 80. – Iss. 3).– p. 78-91. doi: 10.18372/2306-1472.80.14277

The article is recommended for publication by N.B.Chernetska-Beletska, Doctor of Engineering, Professor (Ukraine).

Received 02.06.2020

Accepted 10.06.2020

Н. А. ЛУЖАНСКАЯ

ИМИТАЦИОННОЕ МОДЕЛИРОВАНИЕ И ОПТИМИЗАЦИЯ ГРУЗОВЫХ ТАМОЖЕННЫХ КОМПЛЕКСОВ С ИСПОЛЬЗОВАНИЕМ СИСТЕМ МАССОВОГО ОБСЛУЖИВАНИЯ

Цель работы – создание имитационной модели для исследования и оптимизации структуры грузового таможенного комплекса при выполнении операций по экспорту и импорту грузов, комплексному обслуживанию, размещению грузов на таможенный склад и склад временного хранения. **Методика**– имитационное моделирование систем массового обслуживания. Математическая модель грузового таможенного комплекса представлена в виде системы массового обслуживания. Разработана имитационная модель грузового таможенного комплекса в пакете автоматизации имитационного моделирования GPSS World. Проведено испытание имитационной модели, которое включало два этапа: верификацию и проверку адекватности. При исследовании свойств модели проведена оценка точности имитации, определена длина переходного периода имитации, оценена устойчивость откликов имитационной модели; определена чувствительность откликов модели на изменение интенсивности поступления транспортных средств на обслуживание. **Результаты.** На разработанной имитационной модели проведено исследование процессов таможенно-логистического обслуживания грузовладельцев при экспорте и импорте грузов, комплексном обслуживании, размещении грузов на таможенный склад и склад временного хранения. Представлены результаты апробация имитационной модели на одном из грузовых таможенных комплексов Киевской области. **Научная новизна** – возможность исследовать на разных уровнях детализации и во времени процессы грузовых таможенных комплексов с помощью имитационного моделирования, оптимизируя его структуру. **Практическая значимость.** Разработанная имитационная модель грузового таможенного комплекса предоставляет возможность определять среднее время пребывания транспортных средств на территории грузового таможенного комплекса при выполнении операций по экспорту и импорту грузов, комплексному обслуживанию, размещению грузов на таможенный склад и склад временного хранения; вероятность отказа в обслуживании ввиду отсутствия мест для стоянки транспортных средств в зоне таможенного контроля; оптимальное количество таможенных инспекторов и мест для стоянки транспортных средств; оптимальные размеры складских площадей для размещения груза на таможенный склад или склад временного хранения. Это позволит не только провести анализ работы грузового таможенного комплекса, но и оптимизировать его структуру, определить действия, которые позволят увеличить пропускную способность грузового таможенного комплекса.

Ключевые слова: грузовой таможенный комплекс; имитационное моделирование; системы массового обслуживания

Н. О. ЛУЖАНСЬКА

ІМІТАЦІЙНЕ МОДЕЛЮВАННЯ ТА ОПТИМІЗАЦІЯ ВАНТАЖНИХ МИТНИХ КОМПЛЕКСІВ З ВИКОРИСТАННЯМ СИСТЕМ МАСОВОГО ОБСЛУГОВУВАННЯ

Мета роботи – створення імітаційної моделі для дослідження і оптимізації структури вантажного митного комплексу при виконанні операцій з експорту та імпорту вантажів, комплексного обслуговування, розміщення вантажів на митний склад і склад тимчасового зберігання. **Методика**– імітаційне моделювання систем масового обслуговування. Математична модель вантажного митного комплексу представлена у вигляді системи масового обслуговування. Розроблено імітаційну модель вантажного митного комплексу в пакеті автоматизації імітаційного моделювання GPSS World. Проведено випробування імітаційної моделі, котра включала два етапи: верифікацію и перевірку адекватності. При дослідженні властивостей моделі проведена оцінка точності імітації, визначена довжина перехідного періоду імітації, оцінена стійкість відгуків імітаційної моделі; визначена чутливість відгуків моделі на зміну інтенсивності надходження транспортних засобів на обслуговування. **Результати**. На розробленій імітаційній моделі проведено дослідження процесів митно-логістичного обслуговування вантажовласників при експорті та імпорті вантажів, комплексному обслуговуванні, розміщенні вантажів на митний склад і склад тимчасового зберігання. Представлені результати апробації імітаційної моделі на одному з вантажних митних комплексів Київської області. **Наукова новизна**– можливість досліджувати на різних рівнях деталізації і в часі процеси вантажних митних комплексів за допомогою імітаційного моделювання, оптимізуючи його структуру. **Практична значимість.** Розроблена імітаційна модель вантажного митного комплексу надає можливість: визначати середній час перебування транспортних засобів на території вантажного митного комплексу при виконанні операцій з експорту та імпорту вантажів, комплексного обслуговування, розміщення вантажів на митний склад і склад тимчасового зберігання; ймовірність відмови в обслуговуванні через відсутність місць для стоянки транспортних засобів в зоні митного контролю; оптимальну кількість митних інспекторів і місць для стоянки транспортних засобів; оптимальні розміри складських площ для розміщення вантажу на митний склад або склад тимчасового зберігання. Це дозволить не тільки провести аналіз роботи вантажного митного комплексу, а й оптимізувати його структуру, визначити дії, які дозволять збільшити пропускну спроможність вантажного митного комплексу.

Ключові слова: вантажний митний комплекс; імітаційне моделювання; системи масового обслуговування