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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

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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.
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 the opportunity 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 ($q_k$), average queuing time ($w_k$), and server load factors ($\psi_k$) are determined. Then, for each server, the value of the time loss of vehicle service requests in queues is calculated:

$$LT_k = \eta_k \cdot W_k$$ (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 ($LT_k; \psi_k$) are considered the bottlenecks of the freight customs complex.

Devices that have maximum $LT_k$ values and minimum $\psi_k$ 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).

![Fig. 2. Simulation Results in GPSS](image-url)
Table 1

| Freight customs complex modeling results |
|------------------------------------------|
| Inspector | Parking in the customs control zone | Parking for detained vehicles | Comprehensive service warehouse | Customs warehouse | Temporary storage warehouse |
| PR₁ | PR₂ | PR₃ | PR₄ | PR₅ | PR₆ |
| Load factor $\psi_{l}$ | 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 $\psi_{l}$ | 12 | 0 | 0,11 | 0,023 | 0,042 | 0,01 |
| Vehicles served without queuing time, % $w_{3}$ | 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 $– 263 \pm 30$ min, if the paperwork is incorrect $– 648 \pm 30$ min;
– import customs clearance $– 263 \pm 30$ min, if the paperwork is incorrect $– 648 \pm 30$ min;
– comprehensive service $– 494 \pm 120$ min,
– stowage of goods in a customs warehouse $– 504 \pm 120$ min;
– stowage of goods in a temporary storage warehouse $– 474 \pm 120$ 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.

Figure 5 shows a diagram of the relationship between the server load intensity and the time loss of vehicle service requests ($LT_{k}$).

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, and the 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 zone and 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.

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ІМІТАЦІЙНЕ МОДЕЛЮВАННЯ І ОПТИМІЗАЦІЯ ГРУЗОВИХ ТАМОЖЕННИХ КОМПЛЕКСОВ С ІСПОЛЬЗОВАНІЕМ СИСТЕМ МАССОВОГО ОБСЛУГОВУВАННЯ

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 таможенной 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 отсчетов 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 таможенной склад и склад временного хранения. Представлены результаты апробации 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 позволяет определить 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 места 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 МАССОВОГО 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 массового обслуговування. Математична модель вантажного митного комплексу представлена у виділені системи массового обслуговування. Розроблено імітаційну модель вантажного митного комплексу в пакеті автоматизації імітаційного моделювання GPSS World. Проведено випробування імітаційної моделі, котра включала два етапи: верифікацію і перевірку адекватності. При дослідженні властивостей моделі проведена оцінка точності імітації, визначена довжина перехідного періоду імітації, оцінена стійкість відгуку імітаційної моделі; визначена чувствительность відгуку моделі на зміну інтенсивності надходження транспортних засобів на обслуговування. Результати. На розробленій імітаційній моделі проведено дослідження процесів митно-логістичного обслуговування вантажовласників при експорти та імпорти 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, оцінюючи його структуру. Практична значимість. Розроблені імітаційні модель вантажного митного комплексу надає можливість: визначити 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 відсутності в обслуговуванні через відсутність місць для стоянки транспортних засобів в зоні митного контролю; оптимальну кількість митних виконавців і місць для стоянки транспортних засобів; оптимальні розміри складських площ для розміщення вантажу на митний склад або склад тимчасового зберігання. Це дозволяє не тільки провести аналіз роботи вантажного митного комплексу, а й оцінювати його структуру, визначити дії, які дозволяють збільшити пропускну спроможність вантажного митного комплексу.

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

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