DEVELOPMENT OF A SIMULATION MODEL OF A CARGO CUSTOMS COMPLEX OPERATION AS A LINK OF A LOGISTIC SUPPLY CHAIN

The main link in the logistics supply chain is the cargo customs complex. It provides customs and logistics services to cargo owners during the export and import of goods, complex services, placement of goods in a customs warehouse and a temporary storage warehouse. To substantiate the choice of the optimal logistics supply chain and optimize the work of the cargo customs complex, it is proposed to use simulation modeling.

The model of operation of the logistics chain and the cargo customs complex is presented in a general form. The proposed model is implemented in the GPSS World simulation automation package. Testing the simulation model involved checking its adequacy. Checking the adequacy of the simulation model, which showed the maximum value of the t-statistic of 1.424 with a critical value of 1.85, proved its compliance with the work of a real object.

After completing the adequacy check, the simulation error was estimated, which was 3 % with an allowable 5 %, due to the presence of pseudo-random number generators in the simulation model. Thus, the simulation error is insignificant for this study.

For the cargo customs complex, an example of the simulation results is given. Based on the results of simulation modeling, it is possible to determine: the optimal type of the logistics supply chain and the optimal structure of the cargo customs complex. A wide range of tasks that the proposed simulation model can solve is presented. Thus, the developed simulation model will make it possible to analyze and improve the modes of operation of the cargo customs complex. In addition, it will allow to get an informed decision regarding the use of a certain type of logistics supply chain

Keywords: logistics chain, simulation model, cargo customs complex, vehicle

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1. Introduction

The favorable geographic location and the extensive network of roads and railways of the country contribute to the development of its transit potential. In addition, the low cost of labor in the country is attractive for locating certain types of production. In the context of the globalization of the world economy, the process of supplying raw materials and goods is becoming increasingly important. The length of the supply chain in the supply chain is increasing and smooth operation becomes more and more critical in the production process.

In modern conditions, taking into account the latest challenges to the world economy, timely delivery of goods is becoming increasingly important. But the delivery process, especially in international traffic, is a rather complicated task.

To solve it, a logistic approach is used, in which the process of delivering goods is considered as a kind of logistic chain.

In a competitive environment in the transport services market, an important place is occupied by the search for rational ways of transport services. This requires the justification of transport and technological schemes for the delivery of goods, the introduction of progressive forms and methods of organizing the transportation process and the provision of related services, the improvement of existing and development of promising technologies for organizing the transport process. Delivery of goods in international traffic can be carried out independently by the cargo owner or with the involvement of intermediaries, combined into a logistics chain. The modern market is characterized by a wide variety not only of the number of subjects of the transport services mar-

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ket, performing the same work in terms of functional load, but also a significant number of forms of their organization. This significantly affects the type and nature of connections between participants in the supply chain.

One of the important links in such a logistics chain is the cargo customs complex (CCC). It is used to carry out operations related to the implementation of customs control and customs clearance of goods and vehicles transported across the customs border of the country. In order to improve the quality and reliability of the operation of the logistics chain, it was proposed to consider the involvement of the CCC into its structure. This will ensure the integration of the links of the logistics chain into a single service system, reduce the duration of customs procedures and financial settlements.

The efficiency of the CCC operation will facilitate the acceleration of customs control procedures and other types of state control, and may help to attract additional volumes of transit traffic.

Global trends in the development of customs and logistics infrastructure provide for the use of progressive methods of delivery of goods and improvement of the CCC operation. Thus, the topic of research, which is aimed at increasing the efficiency of the activities of cargo customs complexes, is relevant.

2. Literature review and problem statement

The work [1] estimates the impact of time delays associated with customs clearance when exporting goods to enterprises. Research results have shown that time delays have a significant negative impact on the export of goods in various directions. But the work does not indicate how these delays are affected by the previous components of the supply chain and how they can be eliminated.

The article [2] assesses the role of customs processes focused on international express delivery of goods. It is noted that the proposed "gravity" model will help to significantly increase trade flows: the introduction of one measure can increase trade flows by 5 %. At the same time, it is not described how this model can be used on the CCC.

The article [3] developed a methodology for the formation of a generalized integral criterion on the basis of technical and economic indicators of the operation of customs infrastructure facilities to assess the efficiency of customs cargo complexes of various levels of technical, technological and organizational support. When forming the integral criterion and the generalized integral criterion, the parameters of the reference cargo customs complex are taken into account. At the same time, each CCC has its own inherent features of operation. It is desirable to take this into account in the simulation model when modeling its work.

The work [4] also notes that the creation of logistics transport and customs complexes makes it possible to simplify and unify the procedures for the clearance of goods. But only the creation and proper operation of the CCC does not ensure the efficiency of the cargo delivery process, since the CCC is only one of the links in the logistics supply chain.

To study complex systems, which are supply chains, it is advisable to use simulation modeling.

There are many different methodologies, as well as a wide range of specialized software systems designed to simulate logistics supply chains and customs infrastructure facilities.

To model the supply chain in [5], a fairly new system modeling language OMG SysML ™ is used. It provides a rich set of specifications for creating models and performing computations, as well as mechanisms for customizing the language for a specific model. One of the disadvantages of this system modeling language is that it is significantly difficult to describe the CCC operation and the inclusion of the CCC in the supply chain as a separate link.

The article [6] proposes an evolutionary algorithm based on simulation modeling and is intended for supply chain planning. This allows to eliminate the negative consequences of accidental and hazardous risk events in the search for production, distribution and transportation of goods. To study the CCC operation, as a component of a certain type of logistics chain, this algorithm is almost impossible to apply, since it is focused more on inventory management, rather than quality of service.

In [7], a decision support system for managing the flow of goods is proposed. The proposed system is developed on the basis of an integrated approach using simulation, optimization and meta-heuristic approaches. However, this work considers only the optimization of the use of containers and warehouse area, does not reflect the full list of works performed at the CCC.

The article [8] presents simulation modeling and analysis of complex multimodal transportation operations with various types of resources. Analysis is the study of various scenarios caused by changes in the source data to measure their impact on the results, including throughput, resource utilization, and latency. At the same time, in this work, only the concept of the simulation model is given, the characteristics of the input stream and the duration of the operations are determined.

Modern publications are devoted to the development of simulation models of transport and logistics infrastructure in the Anylogic system, which has a fairly large functionality. For example, in the article [9], a simulation model of the dynamics of systems based on agents was developed to achieve a stable state of the main parameters of intermodal terminals. But this model does not allow investigating the CCC operation as part of the logistics chain.

The article [10] proposes a simulation model (SM), which can be used to make effective decisions on changing the routes of delivery of goods to the final destination in a crisis. The simulation model evaluates the performance of the supply chain under various redirection strategies. The model can also be used by various recipients of the results. But this model also does not make it possible to include the CCC, as an independent link, in the existing logistics chain.

In [11], a simulation model is developed, where, based on the method of analyzing hierarchies, the problem of choosing a scenario for the development and improvement of the work of the customs terminal complex is considered. As a result of calculations, a priority development scenario was selected and a program for its achievement was determined. This work is not developed, but only notes that it is necessary to develop a simulation model of the logistics process.

In each of the developed simulation models, the CCC is considered as a separate element of the logistics supply chain and does not take into account the influence of other links on the operation of both the CCC itself and the entire logistics chain. Thus, there is a need to develop a simulation model for the CCC operation as a link in the logistics supply chain, with the help of which it would be possible to study various types of logistics chains.

3. The aim and objectives of research

The aim of research is to develop the SM for the CCC operation as a link in the logistics chain. This will provide an opportunity to explore various types of logistic supply chains, a mandatory component of which will be the CCC.

To achieve the aim, the following objectives were set:
– formalize the logistics chain model and its parameters;
– develop a simulation model of the logistics chain and cargo customs complex;
– check the adequacy of the simulation model;
– investigate the properties of the developed simulation model and evaluate the simulation results.

4. Materials and methods of research

Methods of the theory of transport processes and systems and methods of analysis of queuing systems were used to formalize the model of the logistics chain and the CCC. When developing a simulation model, the method of automated simulation modeling and the method of statistical tests were used. In addition, methods of statistical data analysis were also used.

Testing the SM of the supply chain and CCC provides for checking the adequacy of the model [12, 13].

Verification of the adequacy of the logistics supply chain SM to a real object is carried out for the case when it is possible to determine the value of system responses during field tests.

To check the adequacy, the hypothesis is tested about the proximity of the average values of each n-th response of the model $\overline{Y}_n$ to the known average value of the n-th response of a real object $\overline{Y}_{Q_k}^*$. N_1 experiments are carried out on a real object of research and samples of values are formed $\left\{Y_{Q_{nk}}^*\right\}$, $k=\overline{1,N_1}$. N_2 experiments are performed on the simulation model of the system and the sample values $\{Y_{nk}\}$ are obtained using the same n-th model responses $\{Y_{nk}\}$; $k=\overline{1,N_2}$. Usually the sample sizes should be the same ($N_1=N_2$), in some cases $N_1>N_2$.

The samples are used to calculate the estimates of the mathematical expectation and the variance of the model and system responses using the following ratios:

$$\overline{Y}_{Q_n}^* = \frac{1}{N_1}\sum_{k=1}^{N_1}Y_{Q_{nk}}^*; \quad D_n^* = \frac{1}{N_1-1}\sum_{k=1}^{N_1}\left(Y_{Q_{nk}}^* - \overline{Y}_{Q_n}^*\right)^2;$$

$$\overline{Y}_n = \frac{1}{N_2}\sum_{k=1}^{N_2}Y_{nk}; \quad D_n = \frac{1}{N_2-1}\sum_{k=1}^{N_2}\left(Y_{nk} - \overline{Y}_n\right)^2. \quad (1)$$

The basis for testing the hypothesis is the difference $E_n = \left(\overline{Y}_n - \overline{Y}_{Q_n}^*\right)$, in the estimate of the variance of which will be

$$D_{an} = \frac{(N_1-1)D_n + (N_2-1)D_n^*}{N_1+N_2-2}. \quad (2)$$

The values E_n and D_{an} are independent statistics, so t-statistics can be used:

$$t_n = \left(\overline{Y}_n - \overline{Y}_{Q_n}^*\right)\sqrt{\frac{N_1 N_2}{D_{an}(N_1+N_2)}}. \quad (3)$$

With the number of degrees of freedom $\nu=N_1+N_2-2$ and the significance level $\alpha=0.05$, the critical value (t_{cr}) is found according to the Student's distribution tables. If the inequality $t_n \leq t_{cr}$ is satisfied, then the hypothesis about the proximity of the mean values of the n-th response of the model and the real object is accepted. Only if the reviews for all components of the Y and Y_Q^* vectors are close, it is possible to talk about the adequacy of the model and the real object.

After completing the verification of the adequacy of the logistic chain SM and the cargo customs complex, the following estimates were made: simulation errors due to the presence of pseudo-random number generators in the SM; stability of simulation results; sensitivity of SM responses to changes in the input parameters of the model. The GPSS World environment uses random number simulators. GPSS World provides a variety of random number generators, each of which uses a basic generator to simulate uniformly distributed numbers in the interval [0, 1]. Random number generators and the probabilistic nature of SM is a source of simulation error. Usually these two types of errors are difficult to separate. Therefore, a procedure for checking the simulation error is proposed.

At the midpoint of the area of variation of the control parameters X, N runs ($N\geq10$) of the SM are organized with the same values of X and G, but with different initial values of the basic generator. For each k-th run of the SM, the values of the n-th component of the feedback vector are calculated. As a result, samples of feedback values $\{Y_{nk}\}$ are obtained. These samples are used to determine the estimates of the mathematical expectation and variance $\left(\overline{Y}_n, \overline{D}_n\right)$, which are calculated by relations (1). The confidence interval for finding the true value of the mathematical expectation of the n-th component of the MY_n response is determined. At the same time, the distribution of deviations Y_{nk} from MY_n is assumed to be normal. Since the sample sizes are small ($K<30$), then t-statistics are used to find the confidence intervals, it has a Student's distribution:

$$t = \left(\overline{Y}_n - MY_n\right)\sqrt{\frac{(N-1)}{\overline{D}_n}}. \quad (4)$$

The stability of the simulation results is understood as the degree of insensitivity of the IM of the supply chain to changes in the input data. For this purpose, the model responses are compared with an increase in the simulation period. The robustness of the simulation results is assessed by the variance of the feedback. If the variance does not increase with increasing simulation time T_M, the simulation results are stable.

The procedure for assessing the stability of the simulation results is as follows. In the model time t_0, the step Δt is set for quality indicator control – response Y, the number of steps h for control and the expert value of the change in the controlled parameter ΔY_E. After reaching the stationary state, the amplitude of changes in the parameter Y is estimated and the modulus of change in the amplitude ΔY is calculated as a function of h. Each time, the satisfiability of the inequality $|\Delta Y|\leq\Delta Y_E$. If throughout the entire study interval Y is within the specified limits, then the SM is in a stable state. The growth of the spread of the controlled parameter ΔY and the dependence of its value on the change in h indicate the unstable nature of the imitation of the process under study. To study the SM sensitivity, it is necessary to set the range of changes in the response of the model Y when each component of the vector of parameters X changes. If the response of the Y model turns out to be highly sensitive to a change in some component of the vector X, then this

serves as a direct indication of the need to represent it in the model with the highest possible accuracy.

Determination of SM sensitivity to changes in SM parameters is carried out at the central point of the parameter value space. Each q-th component of the vector X deviates from its value at the central point in both directions by the length of the selected interval of its change (min X_q, max X_q). Other components of the parameter vector X remain unchanged and correspond to the center point. A couple of model experiments are carried out and the feedbacks of the MI are calculated for the n-th and component (min Y_q, max Y_q), which mean the values of the responses at the minimum and maximum values of the q-th component of the vector of SM parameters. Next, the increments of the q-th component of the parameter vector (δX_q) and the n-th component of the feedback vector (δY_n), respectively, are calculated using the following relations:

$$\delta X_q = \frac{\left(\max X_q - \min X_q\right) \cdot 2}{\left(\max X_q + \min X_q\right)} \cdot 100\,\%;$$

$$\delta Y_n = \frac{\left|\max Y_n - \min Y_n\right| \cdot 2}{\left(\max Y_n + \min Y_n\right)} \cdot 100\,\%. \qquad (5)$$

The change in the response vector Y can be determined either by the modulus of the growth vector δY_n, or by the maximum value with δY_n. Thus, the sensitivity of the SM of the q-th component of the vector of parameters X is determined by a pair of values $\left(dX_q, \delta Y_q^\circ = \max_n \delta Y_n\right)$. This pair of figures shows by what percentage the SM response can change when the q-th component of the vector of parameters is increased by δX_q percent. Then they do the same with other components of the vector of parameters X. As a result, a set of pairs of values $\{\delta X_q, \delta Y_q\}$ is obtained, where δX_q – the difference of the vector of parameters X. Next, the components of the vector of parameters of the model X are ranked according to the sensitivity of the SM response vector. If the SM turns out to be insensitive for any component of the vector of parameters X, then the change in this component is not included in the plan of the simulation experiment, thereby saving the resource of the simulation time.

5. Development of a simulation model for the cargo customs complex operation as a link in the logistics supply chain

5. 1. Formalization of the model of the cargo customs complex

Vehicles arrive at the CCC to carry out customs and logistics services: customs clearance of export and import of goods, comprehensive services, placement of goods in a customs warehouse and a temporary storage warehouse [14].

The algorithm for performing operations when exporting goods is shown in Fig. 1.

The time intervals between the arrival of vehicles (requests for service) for performing the procedure for exporting goods have a Poisson distribution with intensity λ_i. The vehicles that arrive are waiting for service in the queue until they receive permission to enter the territory of the customs cargo complex. If there are free places and passing weight control ($\alpha\,\%$ of vehicles are denied service due to overload), the vehicles enter the customs control zone, and have N parking spaces. When submitting customs documents, applications are waiting in line. There are M customs inspectors (service devices) working on the territory of the cargo customs complex.

The service time of one vehicle by the inspector is subject to the normal distribution law with the mean m_i and the standard deviation σ_i. With the correct execution of documents, the output flow of vehicles from the customs control zone is formed. $\beta\,\%$ of vehicles arriving at the parking lot for detained cars has K places. If violations are detected, $\gamma\,\%$ of vehicles are moved to the box for in-depth inspection. The rest of the cars, after correcting the documents, form the output flow of vehicles from the customs control zone [15].

Algorithms for performing operations for the import of goods, complex services, placement of goods in a customs warehouse and a temporary storage warehouse have a similar structure.
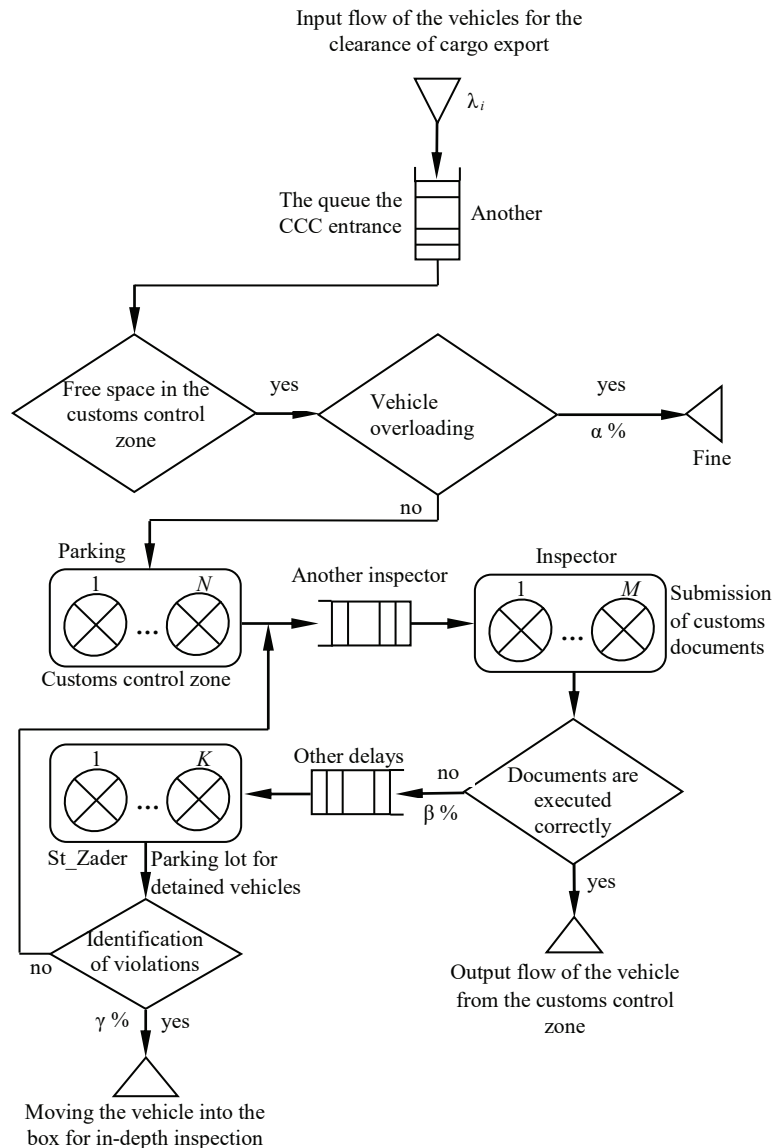

Fig. 1. Algorithm for performing operations when exporting goods

5. 2. Simulation model of the logistics chain and cargo customs complex

In general, the model of the operation of the logistics chain and the CCC can be represented by the structure

$$F = \begin{Bmatrix} S_1, S_2 ..., S_i, ..., S_n \\ U_1, U_2 ..., U_j, .., U_k \end{Bmatrix}, \qquad (6)$$

where S_i – a set of parameters characterizing a separate link in the logistics chain;

U_j – a set of parameters characterizing a separate connection between two links;

n – the total number of links in the logistics chain;

k – the total number of links between links.

A separate link in the supply chain is represented in the model using the structure

$$S_i = \{I_l, X, G\}, i=1, 2, ..., n, \qquad (7)$$

where I_l – the identifier (name) of the link; X – parameters that can be changed when performing experiments; G – parameters that cannot be changed during experiments.

A separate connection between two links of the supply chain is represented in the model using the structure

$$U_j = \{I_U, P_X, P_G\}, j=1, 2, ..., m, \qquad (8)$$

where I_U – the identifier (name) of the link; P_X – parameters characterizing the type of connection; P_G – parameters characterizing the order of the vehicle passing through the connection.

The cargo customs complex in the model is considered as a separate link in the logistics chain.

The input stream is a set of vehicles arriving for service. The parameters of each order Z_l are determined by the structure

$$Z_l = \{Il, T_r, \mathbf{P}, C\}, l=1, 2, ..., n_\mathbf{z}, \qquad (9)$$

where I_l – the identifier of the link; T_r – the moment of application order; $\mathbf{P}$ — vector of order parameters; C – the list of parameters for servicing the order; n_z – the total number of orders.

The interval between orders is modeled according to Poisson's law with intensity λ_i.

The processing of the Z_l order by each individual link is the performance of certain technological operations that must be performed before it leaves the link. Each order is represented in the model using the structure (7).

The duration of each operation is considered as a random variable with a given distribution law. The parameters required for modeling a random variable t are established as a result of statistical processing of field research data. The FIFO (first-in-first-out) order is adopted as the main order of servicing orders.

The parameters of the model (parameters X, which can be changed in the course of field experiments) are:

– λ_i – the intensity of the arrival of vehicles at the customs cargo complex for the implementation of operations for customs and logistics services;

– λ_i – the intensity of the arrival of vehicles for customs clearance of the export of goods;

– λ_2 – the intensity of the arrival of vehicles for customs clearance of the import of goods;

– λ_3 – the intensity of the arrival of vehicles for complex services;

– λ_4 – the intensity of the arrival of vehicles for the placement of goods at the customs warehouse;

– λ_5 – the intensity of the arrival of vehicles for the placement of goods in the temporary storage warehouse;

– options for organizing logistics supply chains (1, 2, 3 or 4 types).

The variables of the model (which can be measured, but cannot be controlled, and which take only those values that are characteristic exclusively for the given object of modeling or the conditions of its operation) are:

– the time taken to complete work by each link in the logistics supply chain;

– the number of customs inspectors;

– the number of parking spaces for vehicles;

– the size of the warehouse for placing the cargo in a customs warehouse or a temporary storage warehouse.

The output characteristics (model responses) are modeling statistics:

– average time (t_i) of work execution by the i-th link of the logistics supply chain;

– total time (t_S) delivery of goods through different supply chains;

– average queue lengths (η_k);

– idle time of vehicles in queues (w_k);

– load factors of servicing devices (ψ_k);

– the number of vehicles serviced without idle time in queues (v_k), %;

– the average service time at the CCC (t_k),

– the average service time at the CCC in case of incorrect paperwork (export and import of goods) (tn_k).

As performance indicators that determine the goals of modeling – the choice of the optimal logistics supply chain, the following are considered:

– average time of work execution by each link of the logistics supply chain;

– total time of delivery of goods through different supply chains.

As the criteria used to determine the optimal structure of the cargo customs complex, the following are considered:

– average idle time of vehicles in service queues;

– maximum and average lengths of service queues;

– load factors of service devices;

– the average residence time of vehicles on the territory of the customs cargo complex when performing operations for the export and import of goods, complex services, placement of goods in a customs warehouse and a temporary storage warehouse;

– the likelihood of denial of service due to the lack of parking spaces for vehicles in the customs control zone;

– the optimal number of customs inspectors and parking spaces for vehicles;

– the optimal dimensions of storage facilities for placing cargo in a customs warehouse or a temporary storage warehouse.

The constraints of the simulation model are related to the conditions imposed on the input flow of vehicles; the absence of phenomena that change the patterns of service time on the CCC of vehicles (failure).

The proposed model for the operation of the logistics chain and the cargo customs complex is implemented in the GPSS World simulation automation package [16, 17]. An example of the text of the simulation model implemented in GPSS World is shown in Fig. 2.

Fig. 2. Partial program listing of the simulation model implemented in GPSS World

Each implementation (model run) has additional innovative tools to make fixing a shorter task;

– GPSS makes it possible to assess the characteristics of the system at certain points in time and at different levels of its detail [16, 17].

5. 3. Checking the adequacy of the simulation model

To check the adequacy, a hypothesis was considered about the proximity of the average values of each model response $\overline{Y}$ to the known average value of the response of a real object $\overline{Y}^{*}$. $N_1=5$ experiments were carried out on a real object of the customs infrastructure and a sample of values $\{Y_i^{*}\}$, $i=\overline{1,5}$ was formed. At the CCC simulation model $N_2=5$ experiments were carried out, according to model responses, the samples were obtained values $\{Y_i\}$; $i=\overline{1,5}$.

The results of full-scale and model experiments, using the example of an operation for customs and logistics services, are presented in Table 1.

Using formulas (1), (2), the estimates of the mathematical expectation and the variance of the model responses were determined, and the estimates of the variance D_{an} were calculated (Table 1). By formula (3), the values of t-statistics t_n are determined. With the number of degrees of freedom $v=N_1+N_2-2=8$ and the significance level $\alpha=0.05$, the critical value $(t_{cr}=1.85)$ was determined according to the Student's distribution tables. Comparing each of the t-statistics values in Table 1 with t_{cr} ($t_n \leq t_{cr}$), the hypothesis about the proximity of the average values of the model responses to the real object of the customs infrastructure is accepted. Thus, it is possible to talk about the adequacy of the simulation model and the real object.

To model systems in GPSS, there is a finite set of abstract components required to describe the elements of a real system and a finite set of standard operations that describe the relationships between the elements. The selected sets of elements and operations are associated with a set of GPSS objects.

Transactions describe the units of flows that are being investigated - cargo and vehicles arriving for service. Transactions move from block to block as the elements they represent move. Each promotion of a transaction triggers some events in the model (registration, etc.). Events are processed by GPSS at a suitable time in model time. Blocks define the logic of the operation of the IM system and determine the paths for the movement of transactions. Almost all changes in the states of the IM occur as a result of the entry of transactions into blocks and the execution of their functions by the blocks.

The use of GPSS for the creation of the DM of the supply chain and the CCC is determined by its wide capabilities:

– GPSS uses a large interface to simplify the MI creation process. This is provided by the capabilities of visualization of the modeling process, as well as built-in elements of statistical data processing;

– GPSS has an interactive model-setting ability that allows to set checkpoints in the model, step-by-step tuning, and the ability to define transaction parameters in the model.

Table 1

Checking the adequacy of the simulation model using the example of customs and logistics services

Re-sponses	Sample values					Average response $\overline{Y}_n, \overline{Y}_n^{*}$	Response variance estimation $\overline{D}_n, \overline{D}_n^{*}$	Variance differ-ence D_{an}	t-sta-tistics t_n
	$j=1$	$j=2$	$j=3$	$j=4$	$j=5$				
Operations for customs and logistics services									
t_{1j}	254.8	256	253.5	255.2	253.8	254.66	1.048	3.874	1.2371
t_{1j}^{*}	255	260	256	253	257	256.2	6.7		
t_{2j}	253.8	255	253.5	254	253	253.86	0.548	2.924	1.4240
t_{2j}^{*}	254	259	255	253	256	255.4	5.3		
t_{3j}	500.2	501	500.1	500.5	500	500.36	0.163	1.4815	0.0520
t_{3j}^{*}	500	503	499	501	499	500.4	2.8		
t_{4j}	352.4	352.6	352	355	354	353.2	1.58	1.29	0.9745
t_{4j}^{*}	353	352	353.5	351	353	352.5	1		
t_{5j}	426.6	426.3	427	426.8	426.9	426.72	0.077	0.8885	0.1342
t_{5j}^{*}	425	426	428	427	428	426.8	1.7		

5. 4. Investigation of the properties of the simulation model of the logistics chain and the cargo customs complex

After checking the adequacy of the SM of the logistics chain and the cargo customs complex, an assessment of the simulation error was carried out.

To determine the error in the responses of the simulation model, 10 simulation experiments were carried out at the midpoint of the values of the parameters of the simulation model. In this case, in the l-th simulation experiment $\left(l=\overline{1,10}\right)$, the parameters of the simulation model did not change, but only the initial values of the algorithms of the basic generators were modified. As a result of the simulation experiment, samples were formed with a volume $N=10$ of each k-th response of the simulation model $\{Y_{nk}\}$. For these samples, estimates of the mathematical expectation and sample variances of model responses $\left(\overline{Y}_n, \overline{D}_n\right)$ were calculated using formula (1). The resulting values of errors dY_n in percent for the simulation model are given in Table 2 calculated by the formula

$$dY_n = \frac{t_{0.05}}{\overline{Y}_n}\sqrt{\frac{\overline{D}_n}{N-1}} \cdot 100\,\%, \qquad (10)$$

where $t_{0.05}$ – the t-statistic value at $(N-1)$ degrees of freedom and significance level $\alpha=0.05$.

The simulation accuracy is determined by the formula

$$d_{SM} = \max_n\{dY_n\}. \qquad (11)$$

Table 2

Estimation of the error of imitation of the responses of the simulation model

Responses	Simulation error $dY_{n\,\%}$
η_1	2.1
w_1	3.0
ψ_1	1.3
η_2	0.8
w_2	1.2
ψ_2	0.9
η_3	1.8
w_3	2.2
ψ_3	1.5
η_4	0.5
w_4	1.1
ψ_4	0.8
η_5	1.7
w_5	2.6
ψ_5	1.9
η_6	1.3
w_6	1.9
ψ_6	1.8
t_1	2.9
t_2	2.8
t_3	2.3
t_4	1.9
t_5	2.2

During a trial simulation experiment, it was found that the upper boundary of the simulation error is $d_{SM}=3\,\%$, which does not exceed $5\,\%$.

To assess the stability of the simulation results using the GPSS debugging and visualization tools, the change in the model time t_0 of the amplitudes of the model responses was controlled. During TM=100800 min=1680 hours for all model responses, no uncontrolled growth was observed. This allowed the developed simulation model to be considered "stable".

To assess the sensitivity of the simulation model, the ranges of changes in the model responses were established when the components of the vector parameters of the model X change: the rate of receipt of vehicles for the customs cargo complex for carrying out operations for customs and logistics services λ_i.

Suppose that the midpoint of the vector of parameters, which corresponds to the intensity of the arrival of vehicles at the CCC, is equal to:

– λ_1=1.71 vehicles/hour – the intensity of the arrival of vehicles for customs clearance when exporting goods;

– λ_2=1.71 vehicles/hour – the intensity of the arrival of vehicles for customs clearance when importing goods;

– λ_3=0.6 vehicles/hour – the intensity of the arrival of vehicles for integrated customs and logistics services;

– λ_4=0.25 vehicles/hour – the intensity of the arrival of vehicles for the placement of goods in the customs warehouse;

– λ_5=0.17 vehicles/hour – the intensity of the arrival of vehicles for the placement of goods in the temporary storage warehouse.

The responses checked for sensitivity were recorded: Y_{VMK}=(η_k, w_k, ψ_k, ν_k, , t_l, tn_l).

Let's select the ranges of changes in the intensity of the arrival of vehicles at the cargo customs complex:

– from 1.43 vehicles/hour up to 2.14 vehicles/hour for λ_1;

– from 1.43 vehicles/hour up to 2.14 vehicles/hour for λ_2;

– from 0.5 vehicles/hour up to 0.75 vehicles/hour for λ_3;

– from 0.2 vehicles/hour up to 0.3 vehicles/hour for λ_4;

– from 0.14 vehicles/hour up to 0.21 vehicles/hour for λ_5.

The responses of the simulation model with varying λ_i are given in Table 3.

The increase in the components of the vector of parameters and the components of the vector of reviews are determined by the formula (5).

The calculation results are shown in Table 4.

The maximum sensitivity of the model (100 %) with a 40 % change in the intensity of the arrival of vehicles for customs clearance λ_1 export and λ_2 import of goods is achieved according to reviews η_1 and w_1 (average queue length and average waiting time in a queue to a customs inspector), ψ_2, η_2, w_2, ψ_3, η_3, w_3 (load factor of parking in the customs control zone and parking for detained vehicles, average queue length and average waiting time in queue for entering the VMK and parking for detained vehicles), as well as t_1 and t_2 (average time of customs clearance of export and import of goods).

The highest sensitivity of the simulation model (100 %) when the intensity of the arrival of vehicles for complex customs and logistics services λ_3 changes by 40 % is achieved according to reviews η_4 and w_4 (average queue length and average waiting time in a queue at a commercial warehouse). Other responses of the model, including the average time of complex customs and logistics services t_3, are insensitive to the increase (λ_3).

A 40 % change in the intensity of the arrival of vehicles for placing cargo at the customs warehouse λ_4 leads to a change in the responses η_3 (average length of the queue at the entrance to the CCC), η_5 and w_5 (average length of the queue and average idle time in the queue), as well as t_4 (average time of placement of goods and customs warehouse) by 100 %.

Table 3

Input data for testing the sensitivity of the simulation model

No.	1	2	3	4	5	6	7	8	9	10
λ_1	**2.14**	**1.43**	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71
λ_2	1.71	1.71	**2.14**	**1.43**	1.71	1.71	1.71	1.71	1.71	1.71
λ_3	0.6	0.6	0.6	0.6	**0.75**	**0.5**	0.6	0.6	0.6	0.6
λ_4	0.25	0.25	0.25	0.25	0.25	0.25	**0.3**	**0.2**	0.25	0.25
λ_5	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	**0.21**	**0.14**
ψ_1	1	0.864	1	0.859	0.952	0.9	0.933	0.912	0.919	0.905
w_1	521	3.85	528.7	3.56	17.7	6.3	11.2	7.64	8.9	6.81
η_1	439.5	0.28	44.1	0.26	1.4	0.47	0.87	0.581	0.68	0.513
ψ_2	0.978	0.165	0.991	0.165	0.203	0.175	0.189	0.179	0.183	0.177
w_2	231.9	0	239.2	0	0	0	0	0	0	0
η_2	16.6	0	17.1	0	0	0	0	0	0	0
ψ_3	0.942	0.258	0.938	0.251	0.297	0.282	0.29	0.284	0.282	0.28
w_3	1142	0.096	760.8	0.06	0.165	0.122	0.24	0.118	0.092	0.076
η_3	10.4	0.01	6.9	0	0.01	0.01	0.02	0.001	0.001	0.001
ψ_4	0.726	0.724	0.727	0.723	0.905	0.605	0.726	0.728	0.725	0.723
w_4	0.31	0.29	0.221	0.265	15.38	0.02	0.228	0.266	0.265	0.304
η_4	0.03	0.03	0.02	0.03	0.19	0	0.002	0.003	0.003	0.003
ψ_5	0.828	0.829	0.829	0.821	0.828	0.832	0.993	0.662	0.669	0.665
w_5	5.72	4.66	6.41	4.25	4.73	4.43	902.9	0.105	0.058	0.19
η_5	0.023	0.018	0.026	0.017	0.019	0.018	4.27	0	0	0.001
ψ_6	0.569	0.571	0.575	0.57	0.57	0.568	0.569	0.566	0.713	0.474
w_6	0.036	0.018	0.029	0	0.077	0.07	0.118	0.008	0.44	0
η_6	0	0	0	0	0	0	0	0	0.001	0
t_1	965.7	150.9	925.4	149.2	168.3	152.6	159.9	154.7	156.3	153.4
t_2	953.6	150.2	928	148.8	168.6	153.8	160.0	155.2	155.9	153.4
t_3	510.9	490.1	513	489.1	509.3	491.3	493	493.4	492.3	490
t_4	346.3	337.2	347.5	337.2	343	337.6	1238	334.6	335.2	334
t_5	957.1	334.6	966	334.3	349.5	337	342.9	337.8	339.7	337

Table 4

Testing the sensitivity of the simulation model

i	1	2	3	4	5
$\delta\lambda_i, \%$	40	40	40	40	40
$\delta\psi_1, \%$	14.59	15.17	5.62	2.28	1.54
$\delta w_1, \%$	100	100	95	37.79	26.61
$\delta\eta_1, \%$	100	100	99.47	39.83	28
$\delta\psi_2, \%$	100	100	14.81	5.43	3.33
$\delta w_2, \%$	100	100	0	0	0
$\delta\eta_2, \%$	100	100	0	0	0
$\delta\psi_3, \%$	100	100	5.18	2.09	0.71
$\delta w_3, \%$	100	100	29.97	68.16	19.05
$\delta\eta_3, \%$	100	100	0	100	0
$\delta\psi_4, \%$	0.28	0.55	39.74	0.28	0.28
$\delta w_4, \%$	6.67	18.11	100	15.38	13.71
$\delta\eta_4, \%$	0	40.00	100	40.00	0
$\delta\psi_5, \%$	0.12	0.97	0.48	40	0.60
$\delta w_5, \%$	20.42	40.53	6.55	100	100
$\delta\eta_5, \%$	24.39	41.86	5.41	100	0
$\delta\psi_6, \%$	0.35	0.87	0.35	0.53	40.27
$\delta w_6, \%$	66.67	100	9.52	100	100
$\delta\eta_6, \%$	0	0	0	0	0
$\delta t_1, \%$	100	100	9.78	3.31	1.87
$\delta t_2, \%$	100	100	9.18	3.05	1.62
$\delta t_3, \%$	4.16	4.77	3.60	0.08	0.47
$\delta t_4, \%$	2.66	3.01	1.59	100	0.36
$\delta t_5, \%$	96.38	97.16	3.64	1.50	0.80

A change in the intensity of the arrival of vehicles for placing goods in a temporary storage warehouse λ_5 by 40 % leads to a change in responses w_5 and w_6 (the average waiting time in a queue at a customs warehouse and a temporary storage warehouse) by 100 %.

5. 5. Evaluation of simulation results

In the process of collecting statistics for the simulation of the supply chain, a vector is formed

$$Y_{SCH} = (t_1, \ldots, t_i, \ldots, t_m, t_S), \qquad (12)$$

t_i – the average time of work execution by the i-th $(i = \overline{1,m})$ link of the logistics supply chain; t_S – the total lead time for the delivery of goods through various supply chains.

In the process of collecting statistics on the results of the CCC simulation, a vector is formed

$$Y_{FC} = (\eta_k, w_k, \psi_k, \nu_k, t_l, tn_l), \qquad (13)$$

where η_k – the average length of the queues;

w_k – idle time of vehicles in queues;

ψ_k – load factors of service devices;

ψ_k – the number of vehicles served without waiting in queues %;

k=1 – customs inspector;

k=2 – parking in the customs control zone;

k=3 – parking lot for detained vehicles;

k=4 – warehouse for complex service;

k=5 – customs warehouse;

k=6 – temporary storage warehouse;

t_l – the average time of execution of operations for customs and logistics services at the CCC;

tn_l – the average time of service at the CCC in case of incorrect paperwork (export and import of goods);

l=1 – customs clearance of the export of goods;

l=2 – customs clearance of import of goods;

l=3 – complex service;

l=4 – placement of goods at the customs warehouse;

l=5 – placement of goods in a temporary storage warehouse.

The components of the Y_{FC} vector are determined when performing operations for the export and import of goods, complex services, placement of goods in a customs warehouse and a temporary storage warehouse.

The amount of loss of time spent by vehicles in queues is determined:

$$LT_k = \eta_k \cdot w_k. \qquad (14)$$

For the obtained values, diagrams of the connection between the load intensity of service devices and the losses of the idle time of vehicles in queues are plotted.

Serving devices with the maximum value of a pair of simulation statistics $(LT_k; \psi_k)$ are considered to be "bottlenecks" of the logistics chain and the customs cargo complex. Devices that have maximum LT_k values and minimum ψ_k, values are considered to be places of imbalance in the operation of the logistics chain and CCC.

Based on the analysis and comparison of the diagrams of the connection between the load intensity of service devices and the losses of the idle time of vehicles in queues, the optimal type of the logistics supply chain and the optimal structure of the CCC are selected.

An example of the results of modeling the average time spent by vehicles at the cargo customs complex in the implementation of operations for customs and logistics services are given in Table 5.

Based on the reports obtained as a result of modeling the cargo customs complex, the main indicators of the modeling results were determined and the duration of the idle time of vehicles in queues for service was calculated (Table 6).

Fig. 3 shows a diagram of the relationship between the load intensity of devices and the downtime losses of requests for service in queues LT_k) at the CCC.

Analysis of the obtained simulation results and communication diagrams shows that the "bottleneck" for this CCC is the number of customs inspectors. An increase in their number will increase the capacity of the infrastructure facility and reduce the time for servicing vehicles in the implementation of all operations for customs and logistics services. At the same time, the number of parking spaces for detained vehicles, the area of commercial and customs warehouses, and a temporary storage warehouse is sufficient. The number of parking spaces for vehicles in the customs control zone can be reduced to 30 if an increase in the number of customs inspectors is not possible.
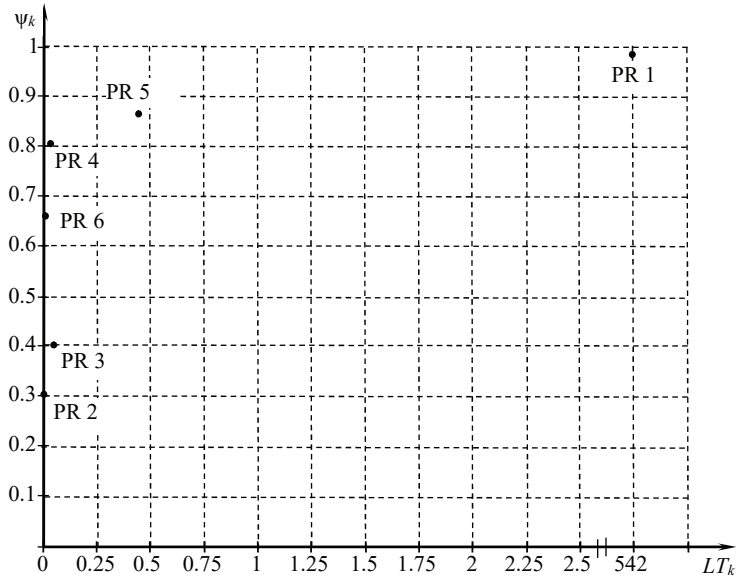

Fig. 3. Diagram of the relationship between the load intensity of serving devices with the loss of time waiting in queues

6. Discussion of the results of the development of a simulation model of the cargo customs complex operation

The advantage of this study is that it was possible to develop a simulation model of the logistics chain, in which the CCC is a separate link. This became possible due to a clear formalization of the model of the CCC operation (Fig. 1).

The simulation model was successfully implemented in the GPSS World simulation automation package, which, in contrast to [9–11], allows one to study the CCC operation as part of the logistics chain. Also, this model makes it possible to study various types of supply chains and obtain the parameters of their operation.

A certain limitation of the developed simulation model is that it can only be applied to supply chains that provide for the presence of a CCC, that is, for the movement of goods in external traffic.

When developing a simulation model, random number generators were used. In this case, the SM itself has a probabilistic nature, which can be a source of imitation error. But at the moment there are no other, more advanced, methods for modeling the processes that occur in the supply chain.

But even with the described shortcomings of the

Table 5

Simulation results when servicing a vehicle at the CCC

Operations for customs and logistics services	Mean service time, min (MEAN)	Standard deviation, min (STD.DEV.)
Customs clearance for the export of goods, t_1	254.8	152.3
– with the correct paperwork	216.2	91.0
– if mistakes were made in paperwork	566.3	185.1
Customs clearance when importing goods, t_2	253.8	148.7
– with the correct paperwork	217.0	91.4
– if mistakes were made in paperwork	558.1	179.0
Integrated customs and logistics services, t_3	500.2	84.9
Placement of goods in a customs warehouse, t_4	352.4	28.4
Placement of goods in a temporary storage warehouse, t_5	426.6	91.6

Table 6

Results of modeling the CCC operation

Key modeling indicators	Customs inspector PR_1	Parking in the zone of customs control PR_2	Parking lot for detained vehicles PR_3	Commercial compo-varehouse PR_4	Customs ware-house PR_5	Temporary storage warehouse PR_6
Load factor, ψ_k	0.989	0.305	0.398	0.806	0.869	0.661
Average queue downtime w_k, min.	80.9	0.0	2.6	2.1	10.6	0.5
Average queue length, η_k	6.7	0.0	0.02	0.02	0.04	0.0
The share of vehicles served without waiting in the queue, v_k, %	9.2 %	100 %	97 %	91 %	61 %	97 %
Duration of vehicle downtime in queues, LT_k, min.	542.03	0	0.052	0.042	0.424	0

SM, the CCC operation, as links in the logistics supply chain, will make it possible to determine the following parameters for the logistics chain as a whole:

– average time of work execution by each link of the logistics supply chain;

– the total lead time for the delivery of goods through various supply chains;

– the type of the optimal logistics supply chain.

The simulation model allows for the determination of:

– the throughput of the cargo customs complex;

– the average time spent by vehicles on the CCC territory, including the time spent in queues;

– the waiting time for vehicles in the queue until the receipt of a permit to enter the territory of the customs infrastructure facility;

– the likelihood of denial of service due to the limitation on the number of vehicles that can simultaneously be located on the territory of the customs cargo complex;

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

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

– the likelihood of refusal to place the goods at a customs warehouse or a temporary storage warehouse, provided that there are no free storage areas;

– the optimal size of warehouse space for placing cargo in a customs warehouse or a temporary storage warehouse, so that the probability of refusal is no more than a certain value;

– the optimal values of the service time for various combinations of the intensity of the given entry of vehicles, which will increase the CCC throughput.

Further improvement of the simulation model can be in a deeper detailing of the processes that occur at the CCC and in general in the supply chain. In addition, one of the possible ways for the development of the simulation model is the visualization of the processes that occur both in the CCC itself and throughout the entire logistics supply chain.

7. Conclusions

1. The model of the logistics supply chain is formalized, which includes a cargo destroy complex. An algorithm for performing operations during the export-import of goods is given. In addition, the parameters, output characteristics and variables of the model are given. Criteria for determining the optimal structure of the CCC and the restrictions imposed on the input flow of vehicles are described.

2. A simulation model of the logistics chain has been developed, in which the cargo customs complex is considered as a separate link. The proposed model allows one to determine the characteristics of logistic chains of various types, on the basis of which one can choose the best option for certain conditions of the CCC operation. Also, a model has been developed that allows to explore and optimize the CCC operation under various conditions of customer service.

3. The tests involved checking the adequacy. For this, the values of the t-statistic t_n are determined. The maximum value of the tn value is 1.424 with its critical value of 1.85. Thus, it is found that the developed simulation model corresponds to the work of the investigated object.

4. Investigation of the properties of the developed simulation model consisted in assessing the error, stability of the simulation results and the sensitivity of the model. During a trial simulation experiment, it was found that the upper boundary of the simulation error is d_{SM}=3 %, which does not exceed the allowable 5 %.

Evaluation of the stability of the simulation results made it possible to consider the developed simulation model "stable", since during TM=1680 hours, for all the responses of the model, their uncontrolled growth was not observed.

The sensitivity assessment made it possible to establish the ranges of changes in the model responses when changing the parameters X: the intensity of the arrival of vehicles to the CCC for carrying out operations for customs and logistics services λ_i.

5. Analysis of the obtained simulation results and communication diagrams shows that the "bottleneck" for this CCC is the number of customs inspectors. An increase in their number will increase the capacity of the infrastructure facility and reduce the time for servicing vehicles in the implementation of all operations for customs and logistics services.

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