UDC 656.135.073
DOI: 10.15587/1729-4061.2024.316568

CONSTRUCTION OF A SIMULATION MODEL OF THE WORK OF A TRANSPORT AND FORWARDING ENTERPRISE IN ORGANIZING MULTIMODAL CARGO TRANSPORTATION

Ievgenii Lebid
PhD, Associate Professor
Department of Transport Law and Logistics**

Nataliia Luzhanska
PhD, Associate Professor*

Iryna Lebid
PhD, Professor*

Alexander Mazurenko
Corresponding author
PhD, Associate Professor***
E-mail: uamazurenko@gmail.com

Maksym Roi
PhD*

Iryna Mykhailenko
PhD
Department of Higher Mathematics
Kharkiv National Automobile and Highway University
Yaroslava Mudroho str., 25, Kharkiv, Ukraine, 61002

Lidiia Yelnikova
PhD***

Oleksii Tihov
PhD Student***

*Department of International Transportation and Customs Control**
**National Transport University
Mykhaila Omelianovycha-Pavlenka str., 1, Kyiv, Ukraine, 01010
***Department of Transport Units
Ukrainian State University of Science and Technologies
Lazaryana str., 2, Dnipro, Ukraine, 49010

The object of this study is the process of rendering transport and forwarding services when organizing multimodal cargo transportation in international traffic.

The task to tackle was predetermined by the need to devise recommendations for choosing the optimal cargo transportation route, taking into account the individual requirements of the customer and performance indicators of the forwarders at the transport and forwarding company.

A simulation model of the work of a transport and forwarding company in the organization of multimodal transportation of goods was built and implemented in the GPSS World simulation automation software. The model involves the optimization of the duration of service provision and makes it possible to determine the required number of transportation department specialists to enable effective cooperation with customers.

When constructing the model, the duration of business processes in the organization of multimodal transportation was taken into account. In addition, the model accounts for the probability of errors and service delays, as well as the average delay time when errors occur, which will make it possible to take into account the additional work time of the forwarder to eliminate them.

The application of the built model in practice will allow specialists at transport and forwarding companies to organize multimodal transportation according to several alternative routes that meet the individual needs of the customer. It will also make it possible to determine the optimal number of forwarders needed to work at the multimodal transportation department.

In this case, the duration of rendering transport and forwarding services will be reduced by 12–16 %, the waiting time in queues for service will decrease by 9–13 %, and the efficiency of the work of specialists at the multimodal transportation department will increase by 9–14 %

Keywords: freight forwarder service, multimodal transportation, simulation model, freight forwarder, customs regime

Received 05.09.2024
Received in revised form 14.11.2024
Accepted 29.11.2024
Published 24.12.2024

***How to Cite:** Lebid, Ie., Luzhanska, N., Lebid, I., Mazurenko, A., Roi, M., Mykhailenko, I., Yelnikova, L., Tihov, O. (2024). Construction of a simulation model of the work of a transport and forwarding enterprise in organizing multimodal cargo transportation. Eastern-European Journal of Enterprise Technologies, 6 (3 (132)), 6–16. https://doi.org/10.15587/1729-4061.2024.316568*

1. Introduction

The high level of competition in the market of transport and forwarding services requires enterprise owners and their employees to use modern approaches to the organization and management of interaction processes with service customers. Formation of the company's strategy involves taking into account market trends and demand for the necessary range of services among customers. Special attention needs to be paid to the organization of multimodal transportation since the freight forwarder needs to plan measures for the interaction of several types of transport [1]. In this regard, a significantly larger number of intermediary organizations is involved, which affects the duration of establishing cooperation, direct provision of services, and elimination of errors that may occur in the service process with a certain probability.

The success of the transportation process depends, first of all, on the clear organization of the interaction of all its participants, and economic efficiency depends on the optimality of the chosen route [2]. Due to the presence of a single control element, for example, a transport-forwarding enterprise (TFE), the transport process becomes more organized. This makes it possible to reduce unproductive idle cargo and vehicles, as well as transportation costs.

The practical experience of TFEs shows that servicing customers with different requests has significant differences in service duration. The key factor influencing the duration of rendering transport and forwarding services is the cargo delivery route. After all, when organizing multimodal transportation, it is important to take into account the distance of transportation, the requirements of transport and customs legislation of countries, as well as the availability and efficiency of logistics infrastructure facilities.

When organizing the export and import of goods, various delivery technologies can be used, which affect the time component of the foreign trade operation as a whole, and the work of a separate forwarder [3]. The stages of implementation and the list of works may differ in duration depending on the degree of complexity of implementation, the possibility of rapid communication with the involved organizations, and the existence of economic barriers in cooperation with counterparties. In order to plan the staffing of the multimodal transportation department, the specificity of activities of the main customers of the enterprise should be taken into account, which directly affects the duration of rendering transport and forwarding services.

Scientific research into this area is important as the improvement of existing services of the enterprise could provide stable demand among existing customers and attract new ones. The development of management concepts regarding the organization of the work of freight forwarders depending on the direction of cargo transportation, the technology of providing services and the time characteristics of the execution of processes will allow for a high level of competitiveness of the enterprise. Achieving this goal is possible with the use of software packages aimed at automating processes that reflect the technological map of the forwarder's work, taking into account the demand for services.

The results of such studies are needed in practice as the implementation of modern management solutions in the work of specialized enterprises may provide an opportunity to assess the impact of the forwarder's work indicators on the efficiency of business processes. In turn, this will make it possible to provide recommendations regarding the choice of the optimal route for the transportation of goods to an individual customer, taking into account their individual needs.

2. Literature review and problem statement

In work [4] it was noted that the global logistics network continues to expand and integrate various types of transport. In particular, the maritime container shipping network has significantly developed to such an extent that its importance in the global supply chain has increased. At the same time, transport services between shippers and consignees remain fragmented. The author emphasizes that the modeling of the global logistics network should include all types of transport involved. But the work does not consider TFE as one of the components of the process of organizing cargo transportation in international traffic.

Work [5] investigated the current market requirements for the transportation of cargo flows and established that multimodal routes meet most of the requirements for the organization of transportation in international traffic. It has been established that the effectiveness of multimodal transportation schemes depends on the quality of TFE operation. The authors have built a multifactorial model that makes it possible to establish the priority of factors affecting the efficiency of TFE resource management. But the model does not provide an opportunity to investigate the influence of the freight forwarder on the organization of cargo transportation in international traffic under different customs regimes.

Simulation models (SMs) are most suitable for the study of transport processes and systems and are the main tool for solving many problems in the field of their management. Thus, in work [6] it is noted that simulation modeling provides an opportunity to research logistics technologies. On the basis of existing logistics technologies using SMs of process, one can choose one that meets all the requirements that must be taken into account when organizing the process of cargo transportation. Unfortunately, the model cannot be used to study the functioning of TFE in the organization of multimodal transportation as it is necessary to carry out research on determining the optimal route for the delivery of goods under different customs regimes.

In work [7], SM of the vehicle operation process was built based on its mathematical model. The presented SM of the operational process makes it possible to evaluate the efficiency of the transport system from the point of view of the selected evaluation criteria: vehicle availability and specific income. This SM cannot be used to study the process of organizing transportation using different types of transport as it is designed to simulate the functioning of a separate vehicle, and not the system as a whole. Also, this SM does not take into account certain features of the organization of transportation under different customs regimes.

In [8], SM was constructed to solve the planning problem in stochastic multimodal freight transportation systems. The model is used to find the optimal schedule for rendering road transport services in the context of multimodal transportation. This SM does not foresee the possibility of researching the influence of the contingent of forwarders and the features of various customs regimes in the organization of international transportation on the main indicators of the quality of the transport process and the determination of optimal routes.

In work [9] it is indicated that the investigation of ways to build an effective transport system is an important component of every study of sustainable development of transport. The authors investigated the efficiency of rail-water intermodal transportation of containers with the help of the built SM in order to research and minimize the total costs in the transportation process. The SM constructed cannot be used for the study of intermodal transportation in which road transport takes part due to certain differences in the technology of interaction with other modes of transport. In addition, the model does not provide an opportunity to research and determine the optimal routes for the transportation of goods, taking into account different customs regimes.

In work [10], the authors indicate that the optimal organization of various types of transport in the container multimodal transportation system directly affects the efficiency indicators. To describe this problem, the authors built an optimization model based on dynamic programming and proposed a dynamic programming algorithm for obtaining an optimal strategy for the combination of modes of transport. This model solves only the issue of the optimal combination of different types of transport for the transportation of certain goods and does not take into account the influence of the quality of the forwarder's work on the results of research. In addition, there is no possibility of research and determination of optimal cargo delivery routes when organizing export or import.

In paper [11], an analysis of existing approaches to modeling the process of interaction of transport market subjects during intermodal transportation of containers was carried out. A mathematical model for the selection of rational strategies for the behavior of TFEs when interacting with transport market subjects under conditions of cooperation has been built. The suggested mathematical model provides an opportunity to consider the maximum number of alternative delivery participants and take into account the amount of external additional profit from the cooperation of participants. But the model is not implemented in the form of SM and cannot be used to simulate the work of TFE when studying the organization of international transportation taking into account different customs regimes.

In work [12], the authors modeled transport processes at a transport forwarding agency by using business process modeling tools and methodology. The transportation process with all the stages associated with it was modeled in specialized software in order to identify bottlenecks, overloads, uneven distribution of workload, excessive expenditure of time, money, etc. The model cannot be used to study the impact of the efficiency of TFE on the organization of multimodal cargo transportation and the search for optimal cargo delivery routes taking into account different customs regimes.

In work [13], the SM of TFE work was built and implemented in the organization of cargo transportation by road transport in international traffic. This model provides for the possibility of research and optimization of organizational and management processes in cooperation with customers of transport and forwarding services. A feature of the constructed SM is taking into account the probability of errors in the forwarder's work and the duration of their elimination. The simulation results reflect the performance indicators of the enterprise in serving different categories of customers. SM makes it possible to evaluate the efficiency of the work of forwarders and to investigate the influence of their number on individual indicators of the efficiency of the organization of the transportation process. This SM is designed only for road transport and cannot be used to study the operation of TFE in the organization of multimodal cargo transportation. Also, it does not provide an opportunity to research and determine the optimal routes of cargo transportation in international traffic for different customs regimes.

Characteristic features of the operation of TFEs are significant differences in their structure and the range of services that can be provided to customers. However, in order to achieve a high level of competitiveness, it is necessary to devise and implement organizational and management measures aimed not only at assessing the general performance indicators of the enterprise but also at detailing them by a separate type of activity. To this end, it is necessary to conduct constant monitoring of all existing departments at the enterprise, both from the point of view of the technology of service provision and the staffing of this process. Therefore, there is a need to build SM that will make it possible to study the impact of staffing on the quality of service provision regarding the organization of the multimodal transportation process and to determine the optimal transportation routes when organizing the import and export of goods.

3. The aim and objectives of the study

The purpose of our work is to build a simulation model of the process of rendering transport and forwarding services in the organization of multimodal transportation of goods along various routes, taking into account the time characteristics of the investigated stages of the forwarder's work. This will make it possible:

– to provide recommendations to the customer on choosing the optimal route for exporting and importing goods;

– to plan the staffing of specialists at the multimodal transportation department, taking into account the demand for their services.

To achieve the goal, the following tasks were set:

– to formalize the TFE work model when organizing multimodal cargo transportation;

– to perform a check of the adequacy of SM of the work of the multimodal transportation department of TFE;

– to optimize the export and import route of the selected product and evaluate the simulation results.

4. The study materials and methods

The object of our study is the process of providing transport and forwarding services in the organization of multimodal transportation during the export and import of goods by various routes.

The research hypothesis assumes that the construction of a simulation model of the work of a transport-forwarding enterprise in the organization of multimodal transportation would make it possible to plan the duration of providing services to exporters and importers, as well as plan the internal business processes at the enterprise.

When investigating the process, the work of TFE was studied, the structure of which includes the department of multimodal transportation. The processes performed by the company's forwarders during the organization of cargo export and import were considered. To meet the needs of customers, specialists devise several alternative options for the delivery of goods, which are characterized by different duration of execution, the probability of errors and delays at a separate stage of service. A significant impact on the researched process is exerted by the average delay time when errors occur, which will require the re-engagement of the forwarder, and therefore service queues will arise.

When building the simulation model, the relevant stages of the business process performed by the freight forwarder when organizing multimodal transportation were taken into account, namely:

1) work planning;

2) acceptance of applications from customers;

3) placement of an application for transportation;

4) control of fulfillment of transportation conditions;

5) exchange of documentation with the customer and the carrier based on the results of the work;

6) analysis of process execution.

5. Determining the optimal cargo transportation route using a simulation model of the organization of multimodal transportation

5. 1. Formalization of the activity model of the transport and forwarding enterprise

The work of TFE is considered, in the structure of which the department of multimodal transportation functions. The procedure for organizing business processes in the implementation of transport and forwarding services for road transportation is considered in work [14], in which its structure is presented.

However, the interaction of different types of transportation involves a slightly more complex technology of customer service, therefore, the work of freight forwarders of the multimodal transport department, unlike the road transport department, will differ in terms of time parameters.

In addition, when organizing multimodal transportation, the number of service stages and intermediary organizations involved in their implementation increases. Accordingly, the factors for evaluating the work of the transport and forwarding company change taking into account the specificity of rendering services and the individual needs of the customer.

The factors on which the functioning of TFE depends were divided into known $A=(a_1, a_2, \dots a_m)$, which can be measured, but cannot be controlled, and controlled factors $X=(x_1, x_2, \dots x_n)$, which can change during experiments. There is another set of factors $U=(u_1, u_2, \dots u_r)$, which reflects possible options for the functioning of TFE for the case when there are conditions whose values are unknown in advance. Let us denote the initial parameters, which depend in a certain way on the vectors A, X and U, as $Y=(y_1, y_2, \dots y_k)$. Thus, Y is a certain function $Y=\Phi(A, X, U)$.

Also, the vector $Z=(z_1, z_2, \dots z_p)$ was introduced into the TFE activity model – it is a vector that characterizes the purpose of modeling and is a criterion for making a certain decision when building the SM of the process of providing transport and forwarding services for the organization of multimodal transportation. This vector depends on the initial parameters Y, i.e.:

$$Z=F(Y)=F(\Phi(A, X, U)). \quad (1)$$

A stream of requests for service is received from customers of transport and forwarding services. Transport and forwarding services are provided under two customs regimes: export and import of goods. Applications for the export of goods have a higher priority.

The processing of the application by the forwarder in the organization of multimodal transportation represents the performance of works W_{ij} according to the stages ST_i, which are given in Table 1. The duration of each activity is considered as a random variable with a given distribution law.

The controlled factors X of the model are:

– α_l is the intensity of application receipt when providing transport and forwarding services under customs regimes l (α_1 – export of goods, α_1 – import of goods);

– PR_l – priority of the application when providing transport and forwarding services under customs regimes l;

– RT_k – the choice of route k when organizing multimodal cargo transportation.

Table 1

Types of freight forwarder's activities in the organization of multimodal transportation

Activity ID	Activity title
ST_1	Stage 1. Work planning
W_{11}	Acceptance and consideration of the Customer's order
W_{12}	Route planning
W_{13}	Evaluation and selection of carriers
W_{14}	Formation of a commercial offer to the Customer
ST_2	Stage 2. Acceptance of applications from the Customer
W_{21}	Obtaining an official order for the performance of transportation services or TEO
W_{22}	Signing a contract for transportation or TEO with the Customer
ST_3	Stage 3. Placing an application for transportation
W_{31}	Signing a contract for transportation
W_{32}	Placing an application (booking) in the shipping line
ST_4	Stage 4. Control of fulfillment of transportation conditions
W_{41}	Issuance of transport documents
W_{42}	Carrying out load control
W_{43}	Control of the location of the vessel with the container along the transportation route
W_{44}	Issuance of preliminary invoices to the Customer for transportation
W_{45}	Informing the customs department about the terms of cargo arrival
W_{46}	Carrying out control of customs clearance of goods
W_{47}	Control of customs clearance
W_{48}	Organization of transportation by the following mode of transport (if necessary)
W_{49}	Carrying out control of the unloading of goods
ST_5	Stage 5. Exchange of documentation with the Customer and with the carrier based on the results of the work
W_{51}	Exchange of documents with the carrier
W_{52}	Organization of the creation of an account for the Customer
W_{53}	Exchange of documents with the Customer
ST_6	Stage 6. Analysis of process execution
W_{61}	Closing the application
W_{62}	Settlement of inconsistencies in the process of service provision
W_{63}	Settlement of claims of the Customer

Factors A of the model are:

– n – the number of TFE forwarders when providing transport and forwarding services;

– $m_{ij}\pm\sigma_{ij}$ – estimation of the average time of execution of the jth activity W_{ij} of the ith stage ST_i (Table 1).

The U factors of the model are:

– γ_{ij} is the probability of errors by forwarders when performing the jth activity W_{ij} of the i-th stage ST_i;

– λ_{ij} – the probability of delay in execution of j-th activity W_{ij} of i-th stage ST_i.

The initial characteristics Y of the model are:

– t_k – duration of the transport and forwarding service for the k-th route RT_k;

– w_k – waiting time in the queue for transport and forwarding service for the k-th route RT_k;

– η – the length of the queue for transport and forwarding services;

– ν_k – the share of requests served without downtime in the queue for the k-th route RT_k;

– p_k – reliability of providing transport and forwarding services for the k-th route RT_k;

– ψ – load factor of freight forwarders;

– ρ – the average number of employed forwarders ρ.

The responses of model Y and the following indicators are considered as performance indicators Z, which determine the goals of modeling:

– n^* – the optimal number of forwarders to work at the TFE multimodal transportation department;

– RT^* – the optimal route for the organization of multimodal cargo transportation;

– Δt_k – reduction of the duration of the transport and forwarding service for the k-th route RT_k;

– Δp_k – increase in the reliability of the provision of transport and forwarding services for the k-th route RT_k;

– $\Delta\gamma_{ij}$ – reduction of the probability of errors by forwarders when performing the j-th activity W_{ij} of the ith stage ST_i;

– $\Delta\lambda_{ij}$ – reduction of the probability of delays in execution of the j-th activity W_{ij} of the i-th stage ST_i.

5. 2. Verifying the adequacy of the simulation model and estimating the simulation error

It is proposed to use the theory of mass service to study the activities of the enterprise providing transport and forwarding services in the organization of multimodal transportation of goods along various routes. The block diagram of work on rendering transport and forwarding services is shown in Fig. 1.

The proposed model of TFE activity is implemented in the GPSS World simulation automation software [15]. An example of the text of the SM activity of TFE in GPSS World is shown in Fig. 2.

GPSS World provides the possibility of step-by-step debugging of the model (Fig. 3).

GPSS World has a high degree of interactivity when debugging the model, that is, visual control over the passage of applications through the blocks of the GPSS model with the analysis of their values and parameters.

The verification of the adequacy of SM was carried out for the case when it is possible to determine the value of the system responses during field tests.

To check the adequacy of the model, the hypothesis that the average values of each response of the model $\overline{Y}$ are close to the known average value of the response of the real object $\overline{Y}^*$ was tested. $N_1=5$ experiments were conducted on a real object and a sample of $\{Y_i^*\}$ values $i=\overline{1,5}$. was formed. $N_2=5$ experiments were conducted with the help of SM, samples of $\{Y_i\}$; $i=\overline{1,5}$. values were obtained based on the feedback of the model.

The results of full-scale and model experiments are given in Table 2.

Estimates of the mathematical expectation and variance of the model and system responses (Table 2) were determined by the samples using the following ratios:

$$\overline{Y}^*_{Q_n}=\frac{1}{N_1}\sum_{k=1}^{N_1}Y^*_{Q_{nk}};$$

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

$$\overline{Y}_n=\frac{1}{N_2}\sum_{k=1}^{N_2}Y_{nk};$$

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

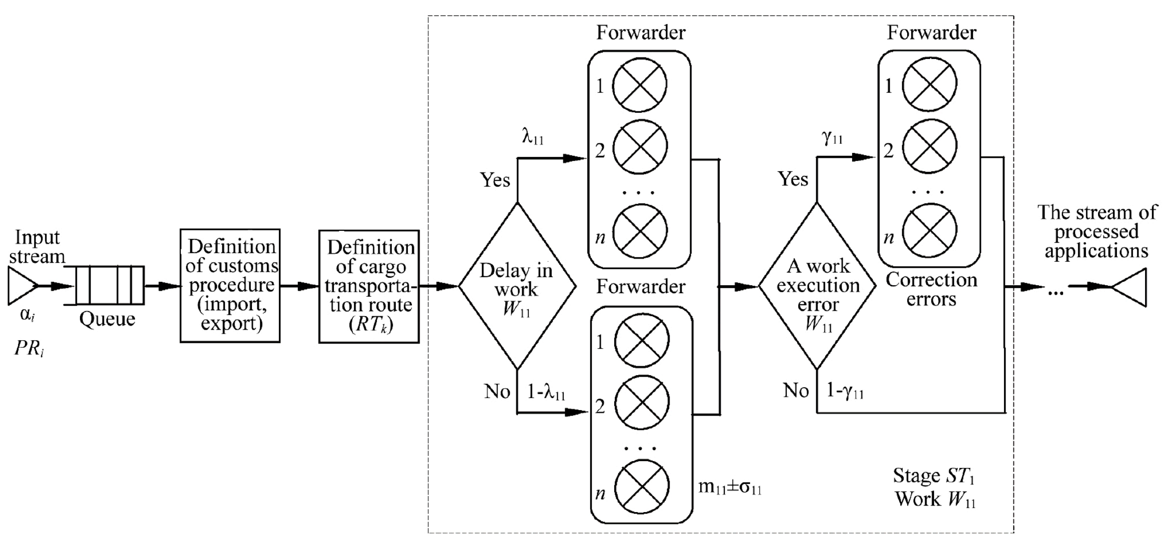

Fig. 1. Block diagram for modeling the work execution process

The basis for testing the hypothesis is the difference $E_n = (\overline{Y}_n - \overline{Y}^*_{Q_n})$, whose variance estimate is:

$$D_{an} = \frac{(N_1 - 1)D_n + (N_2 - 1)D_n^*}{N_1 + N_2 - 2}. \quad (3)$$

The calculated estimates of variance D_{an} are given in Table 2.

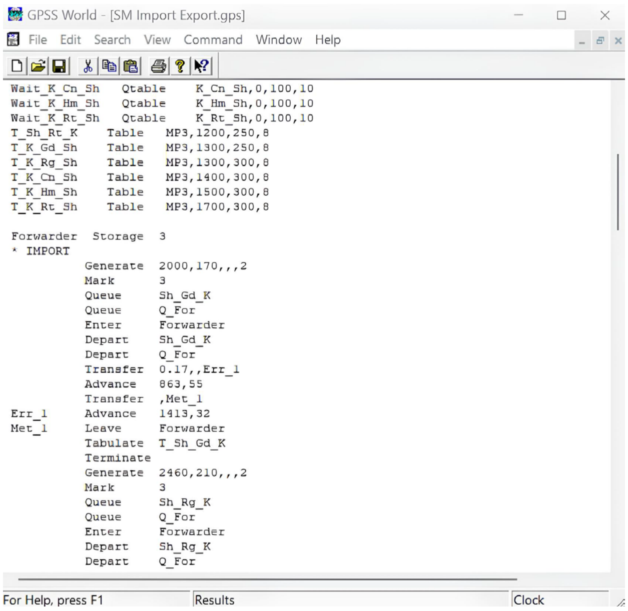

Fig. 2. Partial program listing of the simulation model implemented by the authors in GPSS World

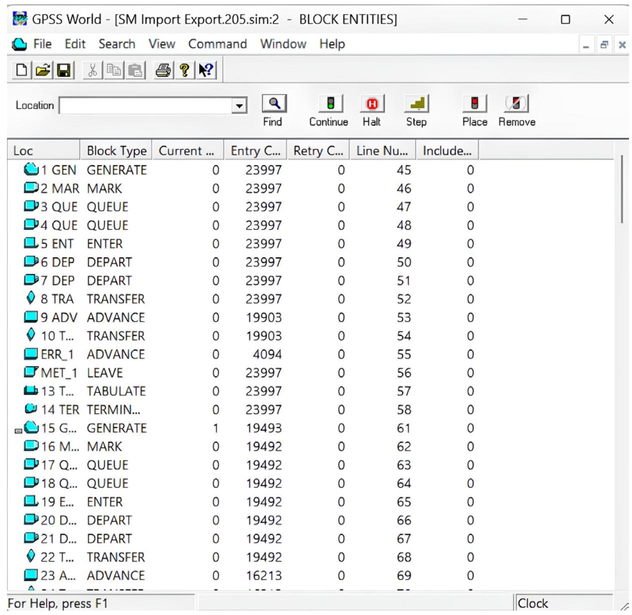

Fig. 3. Step-by-step simulation model debugging window in GPSS World

E_n and D_{an} values are independent statistics, so you can use t-statistics:

$$t_n = \left(\overline{Y}_n - \overline{Y}^*_{Q_n}\right)\sqrt{\frac{N_1 N_2}{D_{an}(N_1 + N_2)}}. \quad (4)$$

Table 2

Verifying the adequacy of the simulation model

Response	Sample component value					$\overline{Y}_n, \overline{Y}^*_n$	$\overline{D}_n, \overline{D}^*_n$	D_{an}	t_n
	$j=1$	$j=2$	$j=3$	$j=4$	$j=5$				
t_{1j}	1,109	1,180	1,115	1,129	1,133	1,133.2	781.2	805	1.1368
t_{1j}^*	1,130	1,122	1,180	1,150	1,186	1,153.6	828.8		
t_{2j}	1,358	1,335	1,336	1,338	1,395	1,352.4	656.3	408.5	1.3456
t_{2j}^*	1,343	1,330	1,332	1,319	1,352	1,335.2	160.7		
t_{3j}	1,397	1,319	1,334	1,376	1,328	1,350.8	1,145.7	962	1.1827
t_{3j}^*	1,352	1,323	1,358	1,315	1,290	1,327.6	778.3		
t_{4j}	1,538	1,522	1,567	1,588	1,550	1,553	654	630.2	0.8817
t_{4j}^*	1,560	1,515	1,534	1,569	1,517	1,539	606.5		
t_{5j}	1,626	1,599	1,610	1,604	1,675	1,622.8	954.7	854.1	1.0388
t_{5j}^*	1,675	1,648	1,659	1,618	1,610	1,642	753.5		
w_{1j}	233	206	305	245	270	252	1,414.7	945.35	0.5760
w_{1j}^*	254	248	298	270	245	263	476		
w_{2j}	245	267	246	236	219	242.6	303.3	698.5	1.2922
w_{2j}^*	277	293	257	284	210	264.2	1,093.7		
w_{3j}	284	226	273	236	287	261.2	799.7	481	1.2112
w_{3j}^*	232	245	265	244	236	244.4	162.3		
w_{4j}	286	268	218	220	268	252	962	587.15	0.9527
w_{4j}^*	234	253	238	215	247	237.4	212.3		
w_{5j}	276	261	243	294	232	261.2	619.7	864.45	0.9895
w_{5j}^*	237	215	248	217	297	242.8	1,109.2		
ψ_j	0.79	0.93	0.88	0.89	0.87	0.872	0.0026	0.00205	1.6064
ψ_j^*	0,83	0,88	0,78	0,84	0,8	0,826	0,0015		

With the number of degrees of freedom $\nu = N_1 + N_2 - 2 = 8$ and the confidence level $\alpha = 0.05$, the critical value (($t_{cr} = 1.85$) was determined according to Student's distribution tables. Comparing each of the t-statistic values in Table 2 with t_{cr} ($t_n \leq t_{cr}$), the hypothesis about the closeness of the average values of the responses of the model and the real object is accepted. Thus, we can talk about the adequacy of SM and the real object.

After checking the adequacy of SM, an estimation of the simulation error was performed, which is caused by the presence of pseudorandom number generators in the SM.

To determine the error of SM responses of TFE activity, 10 simulation experiments were conducted at the midpoint of the SM parameter values. In this case, in the l-th simulation experiment ($l = \overline{1, 10}$), the SM parameters were not changed but only the initial values of the basic generator algorithms were modified. As a result of the simulation experiment, samples with a volume of $N = 10$ of each k-th SM response $\{Y_{nk}\}$ were formed. Based on these samples, mathematical expectation estimates and sample variances of model responses $(\overline{Y}_n, \overline{D}_n)$ were calculated according to formula (2). The resulting error values dY_n in percent for SM are calculated from formula (5); the results of our calculations are given in Table 3:

$$dY_n = \frac{t_{0.05}}{\overline{Y}_n} \sqrt{\frac{\overline{D}_n}{N-1}} \cdot 100\,\%. \qquad (5)$$

The accuracy of the simulation is determined from the formula:

$$d_S = \max_n \{ dY_n \}. \qquad (6)$$

During the trial simulation experiment, it was established that the upper limit of the simulation error is equal to $d_{SM} = 2.8$ % with permissible 5 %. Thus, the simulation error is insignificant for this study.

Table 3

Estimating the simulation error of the feedback simulation model

Response	Simulation error dY_n %	Response	Simulation error dY_n %
t_1	2.3	η_7	1.5
t_2	2.6	η_8	1.3
t_3	2.7	η_9	1.1
t_4	2.8	η_{10}	1.2
t_5	2.2	w_1	2.7
t_6	2.5	w_2	2.2
t_7	2.4	w_3	2.3
t_8	2.2	w_4	1.9
t_9	2.3	w_5	1.8
t_{10}	0.9	w_6	1.7
η_1	1.5	w_7	2.6
η_2	1.8	w_8	2.3
η_3	1.2	w_9	2.2
η_4	1.5	w_{10}	1.9
η_5	0.8	Ψ	0.9
η_6	0.9	P	1.0

5. 3. Determining the optimal cargo transportation route when organizing multimodal transportation for different customs regimes

When studying the work of TFE on the organization of multimodal transportation of goods, various routes of cargo delivery were considered, the list of which is given in Table 4.

Table 4

List of cargo delivery routes

Route ID	Route	Route code
	Import	
RT_1	Shanghai – Gdansk – Kyiv	Sh_Gd_K
RT_2	Shanghai – Riga – Kyiv	Sh_Rg_K
RT_3	Shanghai – Constanta – Kyiv	Sh_Cn_K
RT_4	Shanghai – Hamburg – Kyiv	Sh_Hm_K
RT_5	Shanghai – Rotterdam – Kyiv	Sh_Rt_K
	Export	
RT_6	Kyiv – Gdansk – Shanghai	K_Gd_Sh
RT_7	Kyiv – Riga – Shanghai	K_Rg_Sh
RT_8	Kyiv – Constanta – Shanghai	K_Cn_Sh
RT_9	Kyiv – Hamburg – Shanghai	K_Hm_Sh
RT_{10}	Kyiv – Rotterdam – Shanghai	K_Rt_Sh

An example of the screening of the results of TFE simulation of the organization of multimodal transportation of goods along ten routes (RT_1–RT_{10}) under two customs regimes (import, export) is shown in Fig. 4; the interpretation is in Tables 5, 6.

Distribution histograms of service duration by three forwarders according to the export customs regime for the route RT_1 and according to the import customs regime for the route RT_6 are shown in Fig. 5, 6.

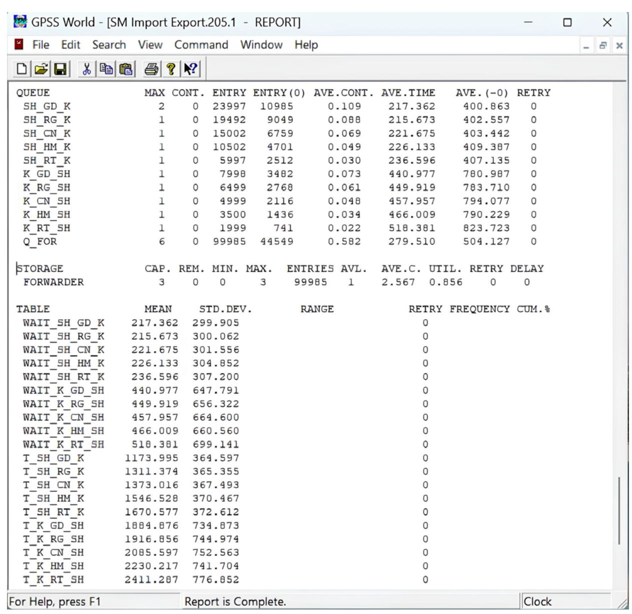

Fig. 4. Screening of simulation results using GPSS World

Table 5

Main indicators for the results of modeling the work of forwarders

Parameter	Parameter value
Number of freight forwarders, n	3
Freight forwarder load factor , ψ	0.856
Average number of freight forwarders employed, ρ	2,57
Average length of the queue for processing the application, η	0.58
Average waiting time in the service queue, min, w	280

Table 6

Main indicators of the results of simulating cargo delivery along routes at n=3

Indicator	Import					Export				
	RT_1	RT_2	RT_3	RT_4	RT_5	RT_6	RT_7	RT_8	RT_9	RT_{10}
t_k, min	1,182	1,313	1,376	1,545	1,682	1,885	1,917	2,086	2,230	2,411
w_k, min	217	216	222	227	237	441	450	458	466	518
ν_k, %	45.0	46.7	44.9	44.5	41.8	43.5	42.6	42.3	41.0	37.1
p_k	0.81	0.78	0.77	0.73	0.71	0.73	0.71	0.69	0.66	0.64

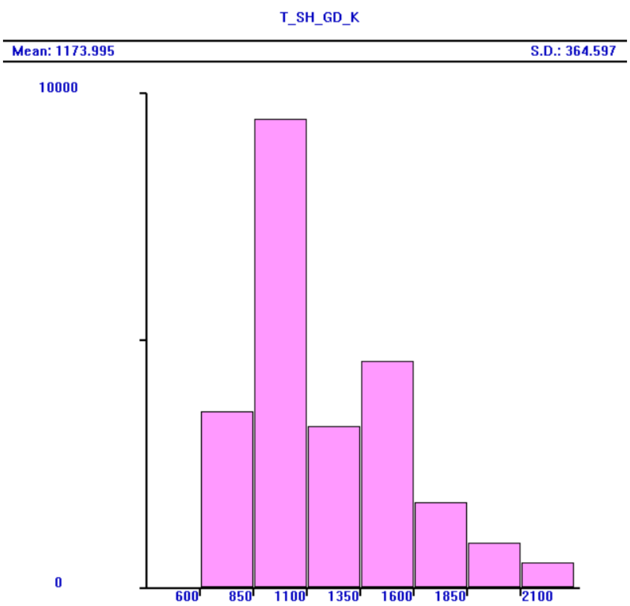

Fig. 5. Distribution of service duration when organizing the export of cargo along the route RT_1

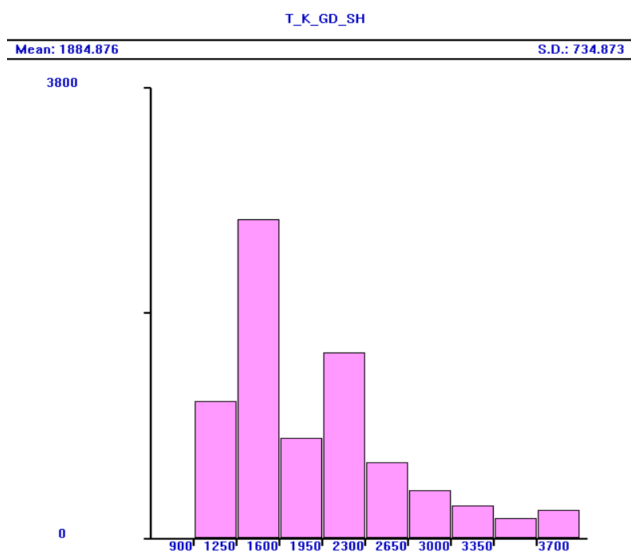

Fig. 6. Distribution of service duration when organizing the import of goods along the route RT_6

Analysis of the above histograms reveals the presence of two modes. The first mode characterizes the average duration of service without errors and delays, the second – in the presence of errors and delays that occur during application processing.

To increase the efficiency of TFE work, it is proposed to increase the number of forwarders; this will reduce the duration of service by reducing the length of the queue and the duration of being in the queue, as well as reducing the probability of errors and delays. The results of modeling the work of TFE when the number of forwarders is increased to n=4 are given in Tables 7, 8.

Table 7

Main indicators for the results of modeling the work of forwarders

Parameter	Parameter value	Parameter change value
Number of freight forwarders, n	4	1
Freight forwarder load factor, ψ	0.622	0.234
Average number of freight forwarders employed, ρ	2.488	0.082
Average length of the queue for processing the application, η	0.093	0.487
Average waiting time in the service queue, min, w	44.6	235.4

Table 8

Main indicators for the results of simulating cargo delivery along routes at $n=4$

Indicator	Import					Export				
	RT_1	RT_2	RT_3	RT_4	RT_5	RT_6	RT_7	RT_8	RT_9	RT_{10}
t_k, min	959	1,099	1,158	1,327	1,447	1,448	1,477	1,627	1,778	1,939
Δt_k, min	223	214	218	218	235	437	440	459	452	472
w_k, min	35.9	35.1	38.4	43.5	49.6	56.1	63.5	62.4	69.8	84.1
Δw_k, min	181.1	180.9	183.6	183.5	187.4	384.9	386.5	395.6	396.2	433.9
ν_k, %	87.2	87.2	85.9	84.0	82.0	83.5	82.3	82.3	81.5	78.8
$\Delta\nu_{k,\%}$	42.2	40.5	41	39.5	40.2	40	39.7	40	40.5	41.7
p_k	0.92	0.91	0.89	0.87	0.85	0.85	0.85	0.83	0.82	0.80
Δp_k	0.11	0.13	0.12	0.14	0.14	0.12	0.14	0.14	0.16	0.16

Distribution histograms of service duration by 4 forwarders according to the export customs regime for the route RT_1 and according to the import customs regime for the route RT_6 are shown in Fig. 7, 8.

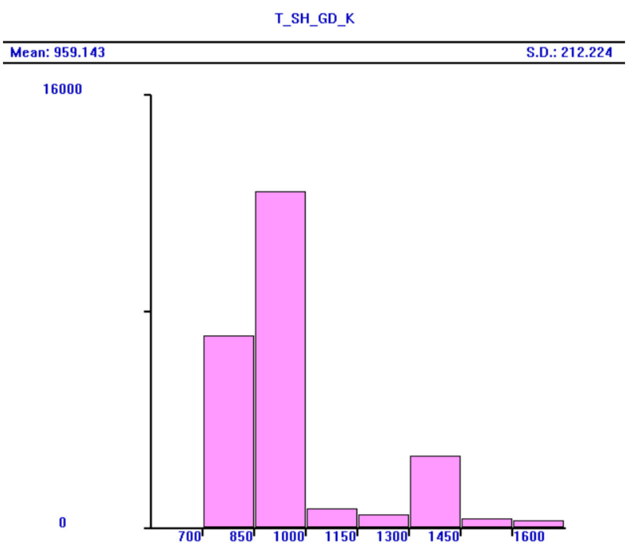

Fig. 7. Distribution of service duration during the organization of cargo export along the route RT_1 (at $n=4$)

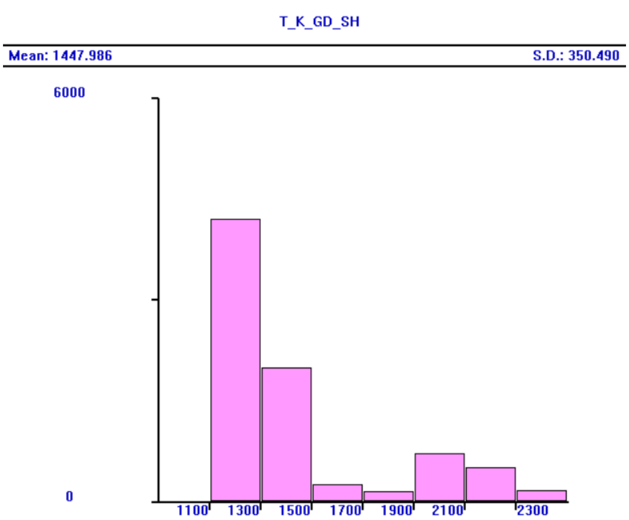

Fig. 8. Distribution of service duration during the organization of cargo import along the route RT_6 (at $n=4$)

The research results allow us to conclude that when the number of forwarders increases to $n=4$, the probability of work delays and the probability of errors by forwarders will decrease, on average, by 6.5 %. At the same time, the duration of transport and forwarding service when organizing the import of goods will decrease, on average, by 15.8 %, and when organizing the export – by 21.6 %. The reliability of rendering transport and forwarding services when organizing the import of goods will increase, on average, by 14.5 %, and when organizing the export – by 17.4 %.

Based on our results of the research, it can be concluded that according to the selected parameters, the optimal route for exporting goods from Shanghai by road and sea transport is Shanghai – Gdansk – Kyiv. This direction of transportation indicates a well-established communication system with the chosen technology of goods delivery. In turn, when importing goods to Shanghai, it is advisable to recommend to customers the routes Kyiv – Gdansk – Shanghai, Kyiv – Riga – Shanghai.

6. Discussion of results of simulating the model for the selection of a transport and forwarding company to meet the needs of the customer

The results of modeling make it possible to provide recommendations to individual customers based on their individual needs regarding the organization of export or import of goods. This will make it possible to carry out a comparative analysis of the performance indicators of the organization of a multimodal flight according to several route options, among which the optimal route should be chosen. In addition, the developed software package makes it possible to analyze several alternatives at the same time and take into account the most important factors depending on the customs regime of goods delivery.

A significant advantage of foreign trade operations is the effective organization of all processes related to their implementation and the establishment of interaction between all involved organizations. In this process, the key tasks of developing an algorithm of actions at all stages of the delivery of goods in international communication are entrusted to the forwarder and depend on their experience and acquired competences. In contrast to [4, 5], when studying the list and structure of works performed by the forwarder taking into account the needs of the customer, it was possible to establish their time characteristics and the probability of errors and delays in delivery. Thus, it will be possible to more accurately plan the duration of the foreign trade operation at the stage of preparation for transportation.

Our proposed technological advancement, in contrast to [6, 7], allows transport and forwarding companies to provide recommendations to customers regarding the choice of the optimal route for the delivery of goods under different customs regimes. In addition, the model built, in comparison to [8], makes it possible to plan the staffing of freight forwarders of the multimodal transport department depending on the demand for transport and forwarding services. The provision of transport and forwarding services in the organization of multimodal transportation involving various types of transport involves the performance of works that have certain specificities and differences that are characteristic only for it. Accordingly, the delivery technology, documentation and interaction procedure of the intermediary organizations involved will differ. Therefore, the procedure for choosing the optimal route according to SM, presented in [9, 10], has certain limitations when they are used for the export and import of goods involving road and sea transport. In contrast to [11], our developed SM model makes it possible to evaluate the performance indicators of the transport and forwarding company in the shortest possible time, taking into account the current situation with personnel and existing demand for services. This will make it possible to optimize the company's internal business processes, which will have an impact on the growth of its competitiveness in the market. A significant advantage of the constructed SM in comparison with [12] is the possibility of taking into account the specificity in the organization of multimodal transportation and the influence of performance indicators of forwarders on the choice of the optimal route for the transportation of goods under different customs regimes.

Our results of modeling the work of the multimodal transportation department make it possible to plan the staffing depending on the demand for services and service duration on a separate transportation route. At the same time, the model built makes it possible to change the number of types of activities and stages of service, which are investigated for the purpose of greater detailing of business processes. Many routes that meet the needs of individual customers can be considered at the same time.

In this study, it was possible to build a simulation model of the work of a transport-forwarding enterprise in the organization of multimodal transportation under export and import modes. It makes it possible to determine the indicators of the efficiency in the delivery of goods by alternative routes and to choose among them the optimal one in accordance with the needs of the customer. It also becomes possible to plan the required number of forwarders to work at the multimodal transportation department, taking into account service duration on various routes.

Our SM makes it possible to determine the performance indicators of different numbers of forwarders at the multimodal transportation department (Tables 5, 7), which makes it possible to form a staff of specialists taking into account the demand for services among customers.

Accordingly, the results of modeling the work of the department in the organization of multimodal transportation under various customs regimes, which are given in Tables 6, 8 testify to the possibility of comparing the duration of rendering transport and forwarding services. Based on the received data, the freight forwarder and the customer can make a decision on the delivery according to the route that meets their individual requirements.

The SM built provides for the determination of the optimal route of goods transportation under the given conditions of foreign trade operation and the necessary number of forwarders to enable all stages of service.

The advantages of this study are the possibility of reducing the duration of transport and forwarding services when organizing multimodal transportation by pre-selection of the most optimal route.

The specified characteristics of the work of freight forwarders in the organization of multimodal transportation along different routes indicate significant differences in the indicators of transport and forwarding services for export and import. At the same time, the duration of all stages of activities is shorter in cooperation with seaports of neighboring states, which indicates the established partnership relations.

The main limitations of SM include the need to study interaction with intermediary organizations involved in foreign trade operations, as their internal processes will have a significant impact on the forwarder's work.

The disadvantages of SM are that it does not take into account the possibility of multimodal transportation simultaneously with the involvement of sea, air, and rail transport. It provides only different options for delivery routes for one of those selected as the main transportation.

Future work has the following prospects for building on the current research:

– the possibility of determining the performance indicators of the multimodal transportation department by different types of transport, not only by sea;

– construction of SM for choosing the route of cargo transportation by rail and air transport;

– construction of SM for choosing the mode of transport depending on the goods provided for transportation.

7. Conclusions

1. A model of TFE work for organizing multimodal transportation of goods by road and sea transport with the involvement of seaports of different countries has been formalized. The essence of the model is the possibility of considering several alternative routes at the same time in order to choose the best option among those studied in accordance with the customer's requirements. In addition, the model provides for the determination of the necessary number of forwarders to enable the work of the multimodal transportation department at the transport-forwarding enterprise, depending on the demand for this service among customers.

2. The verification of the adequacy of the SM showed that the upper limit of the simulation error during the test experiment is dSM = 2.8 % with permissible 5 %. Accordingly, the proposed SM of TFE activities for the organization of multimodal transportation reproduces the working conditions of specialized enterprises when performing export and import operations by road and sea transport.

3. The results of the simulation show that among the proposed alternative routes, it is advisable to establish cooperation with the seaports that are closest to the seller or buyer of the goods in terms of their territorial location. Such implementation will reduce the duration of transport and forwarding services for import operations by an average of 15.8 %, and for export operations – by 21.6 %.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Mnatsakanian, M., Shalina, K. (2022). Organizational and technological problems of intelligent interaction of road and sea transport. Scientific Journal of Polonia University, 54 (5), 170–182. https://doi.org/10.23856/5422
2. Zhao, Y., Ioannou, P. A Dessouky, M. M. (2019). Dynamic Multimodal Freight Routing Using a Co-Simulation Optimization Approach. IEEE Transactions on Intelligent Transportation Systems, 20 (7), 2657–2667. https://doi.org/10.1109/tits.2018.2871946
3. Kostiennikov, O. M., Rudovol, P. S. (2017). Pidvyshchennia efektyvnosti orhanizatsiyi multymodalnykh perevezen za rakhunok koordynatsiyi ta kontroliu perevezennia vantazhu. Visnyk ekonomiky transportu i promyslovosti, 58, 95–97. Available at: http://nbuv.gov.ua/UJRN/Vetp_2017_58__53
4. Furuichi, M. (2021). Cross-border logistics practices, policies, and its impact. Global Logistics Network Modelling and Policy, 47–69. https://doi.org/10.1016/b978-0-12-814060-4.00003-4
5. Sokolova, O., Soloviova, O., Borets, I., Vysotska, I. (2021). Development of conceptual provisions to effectively manage the activities of a multimodal transport operator. Eastern-European Journal of Enterprise Technologies, 1 (3 (109)), 38–50. https://doi.org/10.15587/1729-4061.2021.225522
6. Kubasakova, I., Senko, S. (2020). Simulation of Goods Transport. Research and the Future of Telematics, 296–305. https://doi.org/10.1007/978-3-030-59270-7_22
7. Migawa, K., Sołtysiak, A., Czyżewska, M. (2019). Method of assessment of the transport system functioning with the application of the simulation model of the operating process. MATEC Web of Conferences, 302, 01016. https://doi.org/10.1051/matecconf/201930201016
8. Layeb, S. B., Jaoua, A., Jbira, A., Makhlouf, Y. (2018). A simulation-optimization approach for scheduling in stochastic freight transportation. Computers & Industrial Engineering, 126, 99–110. https://doi.org/10.1016/j.cie.2018.09.021
9. Zhao, J., Zhu, X., Wang, L. (2020). Study on Scheme of Outbound Railway Container Organization in Rail-Water Intermodal Transportation. Sustainability, 12 (4), 1519. https://doi.org/10.3390/su12041519
10. Hao, C., Yue, Y. (2016). Optimization on Combination of Transport Routes and Modes on Dynamic Programming for a Container Multimodal Transport System. Procedia Engineering, 137, 382–390. https://doi.org/10.1016/j.proeng.2016.01.272
11. Nahornyi, Ye., Shramenko, N., Orda, A. (2017). Mathematical model of choosing the rational behavior strategies of forwarding service companies when interacting with subjects of transport market on cooperation conditions. Automobile Transport, 40, 12–19. https://doi.org/10.30977/at.2219-8342.2017.40.0.12
12. Popa, C. (2022). The analysis of freight forwarding services using the business process modelling tools. Scientific Bulletin of Naval Academy, XXV (2), 110–116. https://doi.org/10.21279/1454-864x-22-i2-011
13. Lebid, I., Luzhanska, N., Lebid, I., Mazurenko, A., Roi, M., Medvediev, I. et al. (2023). Development of a simulation model of the activities of a transport and forwarding enterprise in the organization of international road cargo transportation. Eastern-European Journal of Enterprise Technologies, 6 (3 (126)), 6–17. https://doi.org/10.15587/1729-4061.2023.291039
14. Lebid, I., Luzhanska, N., Lebid, I., Mazurenko, A., Halona, I., Kovtsur, K. et al. (2024). Selecting a transport and forwarding company for meeting a customer's needs when organizing international road cargo transportation. Eastern-European Journal of Enterprise Technologies, 3 (3 (129)), 55–66. https://doi.org/10.15587/1729-4061.2024.305238
15. GPSS World Reference Manual (2001). Minuteman Software. Holly Springs NC, 305.