UDC 656.135.073
DOI: 10.15587/1729-4061.2023.280886

CONSTRUCTION OF A SIMULATION MODEL OF GOODS DELIVERY IN INTERNATIONAL ROAD TRANSPORTATION TAKING INTO ACCOUNT THE FUNCTIONING EFFICIENCY OF LOGISTICS SUPPLY CHAIN

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The object of this study is the process of goods delivery in international road transport using various types of logistics chains.

The problem being solved is due to the need to develop recommendations for exporters of goods to reformat or design new supply chains during wartime. The expediency of organizing foreign trade operations by the cargo owners' own forces or with the involvement of enterprises providing logistics consulting services is considered.

A simulation model of goods delivery in international road traffic was built and implemented in the GPSS World simulation automation package.

The model involves the optimization of organizational and technological processes related to the activity of both a separate link and the entire supply chain. The study takes into account the components of the time characteristics of the performance of preparatory work when establishing cooperation with institutions and organizations, as well as the direct service of the exporter. The application of the developed model in practical activities will provide an opportunity for exporters to obtain information about the duration and reliability of the stages of a foreign trade operation and the feasibility of involving consulting enterprises in cooperation. At the same time, the simulation results reflect the performance indicators of the proposed supply chains when delivering goods by road transport along various routes. The proposed simulation model will make it possible to reduce the time spent searching for links in the formation of a supply chain by 8–12 %, and the duration of a foreign trade operation by 10–14 %. Thus, the reliability of cooperation with intermediary organizations will increase by 8–11 %

Keywords: supply chain, simulation model, logistics consulting, foreign trade operation, export of goods, intermediary services

Received date 31.03.2023
Accepted date 05.06.2023
Published date 30.06.2023

How to Cite: *Lebid, Ie., Luzhanska, N., Lebid, I., Mazurenko, A., Halona, I., Horban, A., Mykhailenko, I., Medvediev, Ie., Sotnikova, T. (2023). Construction of a simulation model of goods delivery in international road transportation taking into account the functioning efficiency of logistics supply chain. Eastern-European Journal of Enterprise Technologies, 3 (3 (123)), 57–67. doi: https://doi.org/10.15587/1729-4061.2023.280886*

1. Introduction

The issue of the effectiveness of foreign trade operations since the beginning of the war in Ukraine is becoming more and more urgent. The impossibility of delivering goods by sea and air transport requires cargo owners to search for alternative ways of transportation.

Manufacturing and trading enterprises that export goods have faced the complication of fulfilling their obligations to counterparties due to the growing risks associated with the organization of cargo delivery during the war in the country. This was especially noticeable for exporters who had established partnership relations with intermediary organizations, including forwarding, transport, customs brokerage enterprises, and cargo customs complexes.

It is quite difficult for Ukrainian exporters, if necessary, to establish cooperation with new intermediary organizations. The reason for this is the lack of reliable information about the state of their activities as a business entity, the availability of personnel, technical and infrastructure support for the performance of services.

As a result of the formation of such a situation, logistics consulting services began to acquire significant demand on the market. In the pre-war period, the specialization of enterprises providing such services was concentrated on the development of projects of enterprises of the transport and logistics complex and the introduction of system solutions into the activities of already existing enterprises. Currently, a significant share of customer requests is for the preparation of projects for foreign trade operations. The entire complex of works in this direction involves the study and analysis of product sales markets, the formation of a supply chain, and the establishment of cooperation with partner organizations that meet the conditions of foreign trade operations. This will have a significant impact on the formation of the competitiveness of products on potential sales markets, thereby ensuring the profitability of the enterprise from the export of goods. In addition, logistics consulting experts will provide a reliable assessment of the feasibility of cooperation with intermediary organizations on terms favorable to the exporter. This will make it possible to ensure the integration of the links of the logistics chain in accordance with the requirements of the cargo owner, to agree on the optimal cost and duration of service.

Scientific studies on the effectiveness of goods delivery during the war are quite relevant and require the application of effective management solutions. Their main goal is to develop software packages capable of providing clear recommendations to all stakeholders regarding the execution of foreign trade operations in accordance with the needs of the service customer.

The practical implementation of such results will enable exporters to justify the circumstances under which it is expedient to organize the delivery of goods on their own or with the involvement of consulting companies. And also to determine the duration and reliability of the organizational and technological processes of foreign trade operation under the condition of using different types of supply chains.

2. Literature review and problem statement

In work [1] it is noted that the issue of increasing competitiveness is one of the main ones for every enterprise. It is possible to achieve this with the help of logistics, that is, due to the formation of a high-quality logistics system. At the same time, this work is focused only on a single enterprise and does not reveal its influence on the functioning of the logistics supply chain (LSC) as a whole.

Article [2] analyzes the existing methods of increasing the efficiency of the delivery process in distribution systems. To solve the problem of choosing the optimal transport and technological scheme for the delivery of goods, the total cost of funds for the supply of products to consumers under the conditions of the given restrictions was chosen as a criterion. Two mathematical models of the research object are proposed: a single-level monocentric distribution system and a two-level monocentric distribution system. The proposed models do not allow applying them to the conditions of international transportation due to the lack of a number of relevant components of LSC.

Work [3] substantiates the need for research on LSC under modern conditions, which are characterized by the presence of a number of risks. The task of optimizing LSC management in the context of crisis phenomena is considered. The results of the analysis made it possible to identify the risks accompanying the operation of supply chains of industrial enterprises. However, the cited work does not pay attention to the effectiveness of the functioning of individual links of LSC.

Article [4] analyzes the essence, content, and features of logistics consulting. The managerial decision-making process regarding the provision of logistics consulting services is considered, in which the area of influence of the client, the area of operation of the consulting company, and the area of joint decision-making are clearly delineated. The main stages of providing consulting services are shown, the main areas of application of logistics consulting are defined, and their importance in the context of improving the efficiency of logistics business processes is clarified. But the cited article does not specify how the effectiveness of the functioning of individual links of LSC is taken into account.

Work [5] evaluates the impact of temporary delays associated with customs clearance when exporting goods to enterprises. Research results showed that temporary delays have a significant negative impact on the export of goods in various directions. But the cited work does not indicate how these delays are affected by previous components of the logistics chain and how they could be eliminated.

Paper [6] proposed a model for the formation of international LSCs based on a complex multi-criteria analysis of potential cargo transportation routes and the cost of deliveries. The use of a systematic approach to supply planning helps ensure the rational distribution and effective maintenance of cargo flows by the objects of the transport and logistics network. The proposed model can be useful in the activities of transport, logistics, customs brokerage enterprises when justifying alternative routes for the delivery of goods on the basis of multi-criteria analysis of information. The model proposed in the cited work makes it possible to carry out a multi-criteria assessment in the formation of international logistics chains, taking into account potential transportation routes and delivery costs. One of the shortcomings of the developed model is the lack of consideration of the regularities of the impact of organizational and technological measures on the effectiveness of LSC functioning.

Article [7] evaluates the role of customs processes focused on international express delivery of goods. It is noted that the proposed model will help significantly increase the volume of transportation. At the same time, the cited work does not describe how this model could be used in modeling the logistics chain.

Paper [8] proposes an evolutionary algorithm based on simulation modeling (SM) and intended for supply chain planning. This makes it possible to eliminate the negative consequences of random and dangerous risk events during the search, production, distribution and transportation of goods. This algorithm is practically impossible to apply for researching the operation of various types of LSCs as it is focused more on inventory management and not on the efficiency of operation.

In [9], a decision support system for managing product flows is proposed. The proposed system is developed on the basis of an integrated approach using simulation modeling, optimization, and metaheuristic approaches. However, the cited work considers only the optimization of the use of containers and warehouse space, which does not reflect the whole essence of LSC.

In article [10], SM is proposed, which can be used to make effective decisions regarding the change of cargo delivery routes to the final destination in crisis conditions. With the help of a simulation model, the performance of the supply chain under different redirection strategies is evaluated. The model can also be used by different decision makers. But this model does not make it possible to take into account the efficiency of the functioning of individual links of the logistics chain.

Article [11] describes the agent-oriented SM of the supply network. The model allows the interaction between supply chain participants such as manufacturers, middlemen, wholesalers, and retailers to be explored. The model is based on the concept of «agents», which can be software implementations of various participants in the supply chain. A number of studies have been conducted on the influence of various factors on supply chain performance, such as cooperation between chain participants, demand levels, and resource availability. But this SM has limitations in its application only for fairly short LSCs, which are not typical for international transportation.

In each of the reviewed SMs, attention is paid to the functioning of LSCs, but they do not always provide for the possibility of road transportation in international traffic. Different criteria are used to determine the efficiency of functioning but the impact of organizational and technological measures is not taken into account in any way. Therefore, there is a need to develop a simulation model of the functioning of LSC for the delivery of goods in international road transport, taking into account the criterion of the efficiency of the functioning of individual links.

3. The aim and objectives of the study

The purpose of this work is to develop a simulation model of organizational and technological support for the execution of a foreign trade operation, taking into account the duration of the formation of the supply chain and the delivery of goods to the customer. This will make it possible to determine the duration and reliability of goods delivery, taking into account the interests of subjects of foreign economic activity.

To achieve the goal, the following tasks were set:

– to formalize the model of goods delivery in international road transport;

– to develop a simulation model of goods delivery in international road transport;

– to check the adequacy of the simulation model;

– to evaluate the simulation results.

4. The study materials and methods

The object of our study is the process of performing a foreign trade operation by the own forces of production and trade enterprises or with the involvement of enterprises that provide logistics consulting services. When conducting research, the size of the enterprise (large, medium, small, micro) and the possibility of organizing the delivery of the goods through the four most common supply chains on the Ukrainian market are taken into account. Int'ermediaries included in the structure of the supply chain are selected in accordance with the customer's individual conditions regarding cost, duration, quality, and reliability of service.

Intermediary organizations that are involved in the supply chain are forwarding, transport, and customs brokerage companies, cargo customs complexes, checkpoints, as well as customs agencies and logistics centers that are involved in servicing foreign trade operations on the territory of the destination country.

Supply chains are formed according to four types, taking into account the functional support of all the necessary components for ensuring a foreign trade operation:

Type I: Exporter of goods – Forwarding company – Transport company – Customs brokerage company – Warehouse company – Cargo customs complex – Border checkpoint – Customs agent – Logistics center – Importer of goods.

Type II: Exporter of goods – Transport and forwarding company – Customs brokerage company – Warehouse company – Cargo customs complex – Border checkpoint – Customs agent – Logistics center – Importer of goods.

Type III: Exporter of goods – Transport and forwarding company with the presence of a customs broker – Warehouse company – Cargo customs complex – Border checkpoint – Customs agent – Logistics center – Importer of goods.

Type IV: Exporter of goods – Cargo customs complex – Border checkpoint – Customs agent – Logistics center – Importer of goods.

The method of variance analysis (ANOVA – Analysis of Variance) was used to estimate the time of work performed by the links of the supply chain, which is used to test the significance of the difference between the means in different groups by comparing the variance of these groups. Dividing the total variance by several allows us to compare the variance that is caused by between-group differences with the variance that is caused by within-group variability.

To assess the statistical relationship between the type of application (depending on the size of the enterprise and the enterprise's organization of goods export processes) and the average time of completion of work by a link in the supply chain in the «Statistica» software [12], the Kruskel-Wallis criteria were used, which are designed to assess differences in average multiple samples on the level of any trait, and Fisher's test, which is used to assess differences in the variance of multiple samples.

Fig. 1, which was drawn in the GPSS World environment, shows an example of a scale diagram of the average time of completion of work by a link of the supply chain depending on the size of the enterprise.

The results of our calculations (Fig. 1) showed the significance of the effect of the size of the enterprise on the average time of completion of works by a link of the logistics supply chain.

Thus, when modeling supply chains of four types, it is necessary to take into account the size of the enterprise and the organization of the enterprise's processes of exporting goods.

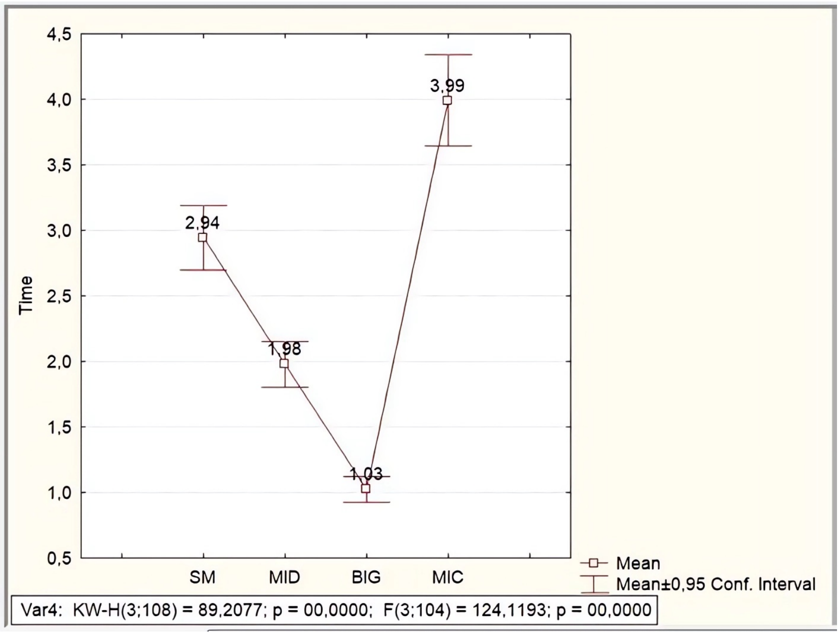


Fig. 1. Chart of the scope of the average service time of a link in the supply chain

5. Development of a simulation model for the delivery of goods in international road transport

5. 1. Formalization of the model of goods delivery in international road transport

Exporters of goods for the implementation of organizational and technological support of foreign trade operations can engage enterprises that provide logistics consulting services or establish cooperation with intermediary organizations on their own.

Depending on the scale of activity of enterprises as exporters, in accordance with the legislation of Ukraine, they can be divided into the following categories: large (more than 250 employees), medium (more than 51–250 employees), small (more than 11–50 employees), micro (up to 10 employees).

The possibility of carrying out a foreign trade operation according to four types of logistics chains, which differ in their structure and involves the following components of time for interaction with each link, is considered:

– time to study information about the activity of the subject of the transport services market; time to assess the reliability of information about the activities of the transport services market entity;

– time for agreeing the terms of service; time to search for alternative service solutions;

– time to assess the reliability of information about alternative solutions; time for agreeing the terms of service according to alternative solutions;

– time to make a final decision regarding service;

– time to complete formalities regarding confirmation of service conditions;

– service time.

The block diagram of the proposed product delivery process is shown in Fig. 2. The exporter of goods separately assesses the duration and reliability of preparatory work on the organization of foreign trade operations and direct delivery of goods, depending on individual requirements.

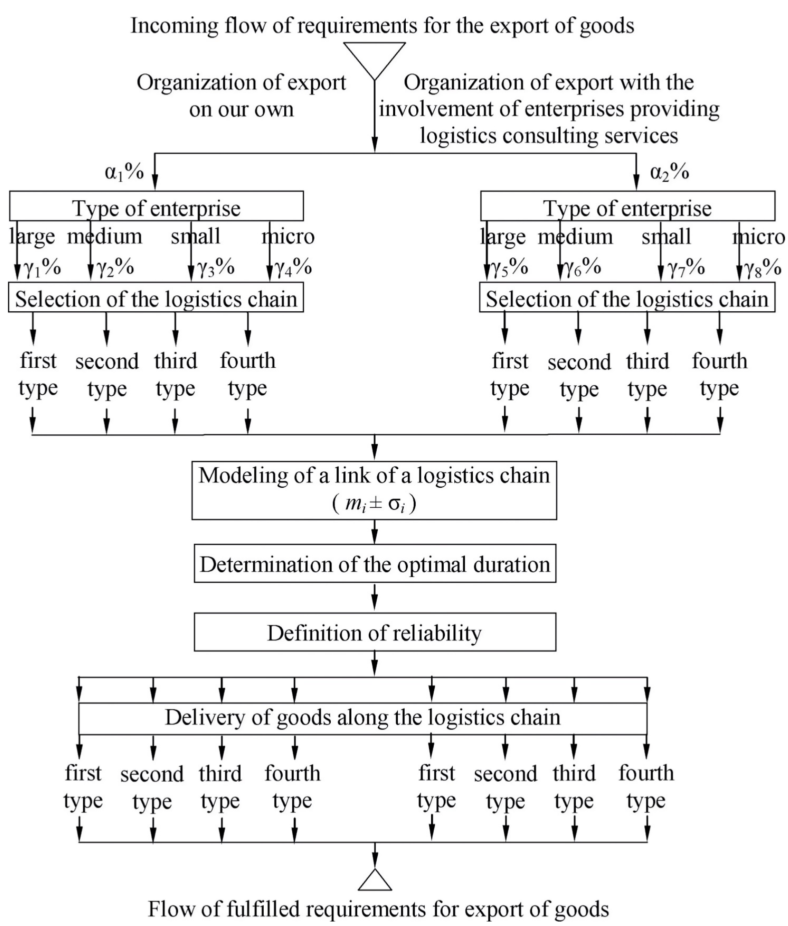


Fig. 2. Flowchart of simulation of the process of delivery of goods

Depending on the distance of transportation, it is possible to determine the impact of the distance of transportation on the reliability of a foreign trade operation.

5. 2. Simulation model of delivery of goods in international road traffic

In general, the model of the functioning of the supply chain can be represented by the structure:

$$F = \begin{Bmatrix} S_1, S_2 ..., S_i, ..., S_n \\ U_1, U_2 ..., U_j, .., U_k \end{Bmatrix}, \quad (1)$$

where S_i is a set of parameters characterizing a separate link of the supply chain; U_j is a set of parameters characterizing a separate connection between two links of the supply chain; n – the total number of supply supply chain; k is the total number of connections between links of the supply chain.

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

$$S_i=\{I_l, P_t, P_{tx}\}, i=1, 2,....., n, \quad (2)$$

where I_l is the identifier (name) of the link; P_t is a set of parameters that characterize the technology of this link; P_{tx} is a set of parameters that characterize the resource provision of the link.

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

$$U_j=\{I_U, X, G\}, j=1, 2,....., k, \quad (3)$$

where I_U is the communication identifier; X – parameters that can be changed during experiments; G are parameters that cannot be changed during experiments.

The processing of an application by each individual link represents the performance of certain technological operations that must be performed before it leaves the link.

The duration of each operation is considered as a random variable with a given distribution law. The parameters necessary for modeling a random variable are established as a result of statistical processing of field research data. FIFO (first-in, first-served) order is adopted as the main order of service of applications.

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

– organization of goods export processes by the enterprise ($\alpha_{1\,\%}$ – with independent organization, $\alpha_{2\,\%}$ – with the involvement of enterprises providing logistics consulting services);

– requests for export of goods from enterprises by size (γ_1, γ_5 – large enterprises, γ_2, γ_6 – medium-sized enterprises, γ_3, γ_7 – small enterprises, γ_4, γ_8 – micro-enterprises);

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

The variables of the model G (which can be measured, but cannot be controlled, and which acquire only those values that are characteristic exclusively of the given modeling object or the conditions of its operation) are: estimation of the average time $m_i \pm \sigma_i$ for the i-th link of the supply chain, depending on the size of enterprises that export goods independently or with the involvement of enterprises that provide logistics consulting services.

The initial characteristics – responses of the model Y are:

– time t_s of preparatory works for the organization of goods delivery depending on: supply chains of four types; enterprise sizes (large enterprises, medium-sized enterprises, small enterprises, micro-enterprises); organization of goods export processes by enterprises (with independent organization, with the involvement of enterprises providing logistics consulting services);

– the total time Ts for the delivery of goods to the customer.

The following are considered as performance indicators that determine the goals of modeling – choosing the optimal supply chain and organization of the enterprise's export process:

– the time of preparatory work for the organization of goods delivery;

– the total time of delivery of goods along various supply chains;

– assessment of the reliability of foreign trade operations.

The proposed supply chain functioning model is implemented in the GPSS World simulation automation package [13].

The set of modeling tools in GPSS World makes it possible to represent the researched SM supply chains of various types and specific characteristics related to the activities of each of its links.

GPSS (General Purpose Simulation System), intended for the simulation of discrete systems, is included in the list of the most common and used in practice means of automation of simulation of mass service systems. The basis of the GPSS language is the transactional method of organizing quasi-parallelism and the method of changing the model time «one step to the next event». The simulation model in GPSS is a sequence of text lines, each of which defines the rules for creating, moving, delaying, and deleting applications or transactions.

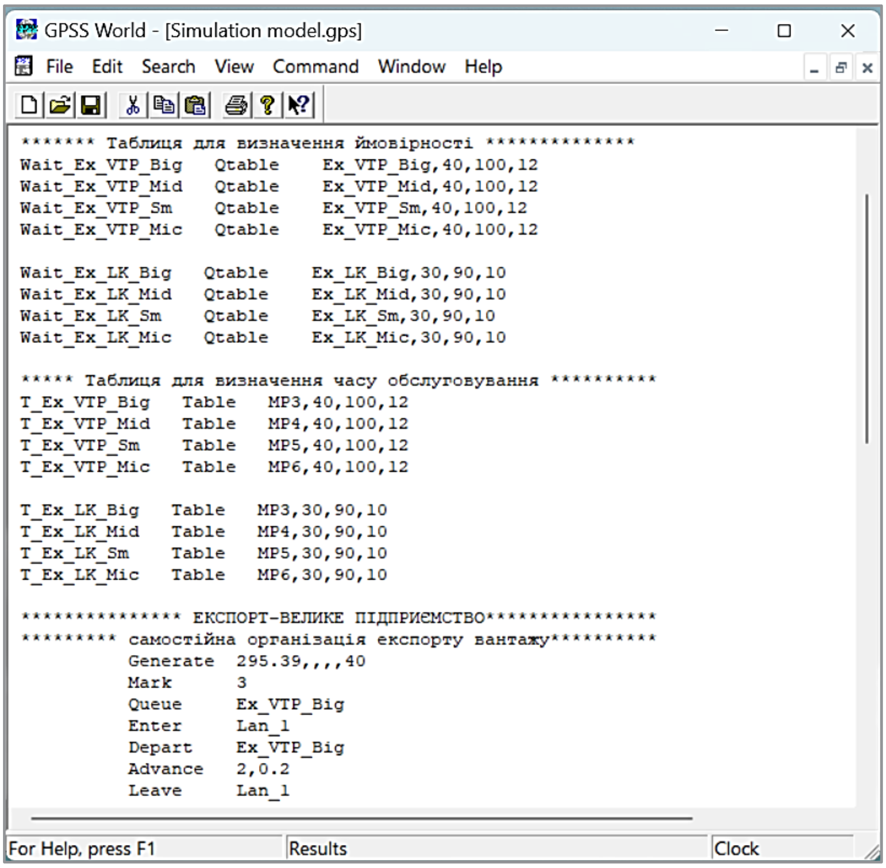
For system modeling in GPSS, a finite set of abstract components necessary to describe the elements of a real system and a finite set of standard operations describing the connections between elements are allocated. Selected sets of elements and operations are matched by a set of GPSS objects.

Transactions describe the units of flows that are investigated – cargo and vehicles arriving for service. Transactions move from block to block as the items they represent move. Each promotion of the transaction initiates some events in the model (registration, etc.). Events are processed by GPSS at the appropriate point in model time. The blocks specify the logic of the simulation model of the system and determine the paths of transaction movement. Practically all changes in the states of the simulation model occur as a result of the entry of transactions into the blocks and the execution of their functions by the blocks.

An example of the text of the simulation model of a logistics chain link in GPSS World is shown in Fig. 3.

The GPSS environment is a machine implementation of the statistical testing method – the Monte Carlo method. Therefore, simulation modeling in this environment allows solving the task of analysis, i.e. evaluation of options for the structure of the supply chain, the impact of changes in various parameters.

Also, this environment allows solving synthesis tasks when it is necessary to create a system with specified reliability characteristics under certain restrictions, which are optimal according to the selected performance evaluation criteria.

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******* Таблиця для визначення ймовірності **************
Wait_Ex_VTP_Big   Qtable    Ex_VTP_Big,40,100,12
Wait_Ex_VTP_Mid   Qtable    Ex_VTP_Mid,40,100,12
Wait_Ex_VTP_Sm    Qtable    Ex_VTP_Sm,40,100,12
Wait_Ex_VTP_Mic   Qtable    Ex_VTP_Mic,40,100,12

Wait_Ex_LK_Big   Qtable    Ex_LK_Big,30,90,10
Wait_Ex_LK_Mid   Qtable    Ex_LK_Mid,30,90,10
Wait_Ex_LK_Sm    Qtable    Ex_LK_Sm,30,90,10
Wait_Ex_LK_Mic   Qtable    Ex_LK_Mic,30,90,10

***** Таблиця для визначення часу обслуговування **********
T_Ex_VTP_Big   Table   MP3,40,100,12
T_Ex_VTP_Mid   Table   MP4,40,100,12
T_Ex_VTP_Sm    Table   MP5,40,100,12
T_Ex_VTP_Mic   Table   MP6,40,100,12

T_Ex_LK_Big   Table   MP3,30,90,10
T_Ex_LK_Mid   Table   MP4,30,90,10
T_Ex_LK_Sm    Table   MP5,30,90,10
T_Ex_LK_Mic   Table   MP6,30,90,10

*************** ЕКСПОРТ-ВЕЛИКЕ ПІДПРИЄМСТВО****************
********* самостійна організація експорту вантажу**********
          Generate  295.39,,,,40
          Mark      3
          Queue     Ex_VTP_Big
          Enter     Lan_1
          Depart    Ex_VTP_Big
          Advance   2,0.2
          Leave     Lan_1
```

Fig. 3. Partial program listing of the simulation model implemented by the authors in GPSS World

5. 3. Checking the adequacy of the simulation model

The verification of the adequacy of the simulation model to the real object 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 about the closeness of the average values of each response of the model $\overline{Y}$ 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 values was formed $\{Y_i^*\}$, $i=\overline{1,5}$. With the help of a simulation model, $N_2=5$ experiments were conducted, samples of $\{Y_i\}$; $i=\overline{1,5}$ values were obtained based on the response of the model.

The results of full-scale and model experiments are given in Table 1.

Table 1

Checking the adequacy of the simulation model

Responses	The value of the components of the sample					Average response value $\overline{Y}_n, \overline{Y}_n^*$	Evaluation of response variance $\overline{D}_n, \overline{D}_n^*$	Difference variance D_{an}	t-statistics t_n
	$j=1$	$j=2$	$j=3$	$j=4$	$j=5$				
t_{1j}	15.03	16	14.9	16.2	14.9	15.406	0.40918	0.44309	0.9169
t_{1j}^*	14.5	15.5	14.6	16	14.5	15.02	0.477		
t_{2j}	19.5	18.7	20.2	18.9	20.3	19.52	0.532	0.315	1.0142
t_{2j}^*	18.9	19	19.5	19.5	18.9	19.16	0.098		
t_{3j}	25.5	24.6	26.3	25.8	23.3	26	1.395	1.8875	1.1509
t_{3j}^*	23	25.1	27	26.4	25	27	2.38		
t_{4j}	32.5	33.6	30.4	31.7	30.3	31.7	1.975	2.8375	0.9386
t_{4j}^*	34	35	32	30	32.5	32.7	3.7		
T_{1j}	63	61	64.5	61.5	64.7	62.94	2.843	6.6075	1.0334
T_{1j}^*	67	59	66.1	65	66	64.62	10.372		
T_{2j}	67.5	65	66.9	65.8	67	66.44	1.033	3.1665	1.0307
T_{2j}^*	70	64	68	67	69	67.6	5.3		
T_{3j}	73.5	72.4	75	74.3	72.9	73.62	1.097	2.1485	1.1650
T_{3j}^*	77	75	74.5	75	72	74.7	3.2		
T_{4j}	80.5	83.7	78.3	83	82	81.5	4.645	4.2975	1.6780
T_{4j}^*	78	82.5	78	78	80	79.3	3.95		

Estimates of the mathematical expectation and variance of the model and system responses (Table 1) were determined by the samples using the following ratios:

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

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

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

$$D_n=\frac{1}{N_2-1}\sum_{k=1}^{N_2}\left(Y_{nk}-\overline{Y}_n\right)^2. \qquad (4)$$

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

$$D_{an}=\frac{(N_1-1)D_n+(N_2-1)D^*_n}{N_1+N_2-2}. \qquad (5)$$

The calculated estimates of variance D_{an} are given in Table 1.

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

$$t_n=\left(\overline{Y}_n-\overline{Y}^*_{Q_n}\right)\sqrt{\frac{N_1N_2}{D_{an}(N_1+N_2)}}. \qquad (6)$$

According to (6), the t-statistics t_n are determined. With the number of degrees of freedom $n=N_1+N_2-2=8$ and the significance level $a=0.05$, the critical value ($t_{critical}=1.85$) was determined according to Student's distribution tables. Comparing each of the t-statistic values in Table 1 with $t_{critical}$ ($t_n \le t_{critical}$), 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 the simulation model and the real object.

To determine the response error of the simulation model, due to the probabilistic nature of the model components and random number generators, 10 simulation experiments were conducted at the midpoint of the values of the simulation model parameters. At the same time, in the l-th simulation experiment ($l=\overline{1,10}$), the parameters of the simulation model were not changed, but only the initial values of the basic generator algorithms were modified. As a result of the simulation experiment, samples with the volume $N=10$ of each k-th response of the simulation model $\{Y_{nk}\}$ 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 (4). The resulting values of errors dY_n in percentages for the simulation model, calculated according to formula (7), are given in Table 2:

$$dY_n=\frac{t_{0.05}}{\overline{Y}_n}\sqrt{\frac{\overline{D}_n}{N-1}}\cdot 100\,\%. \qquad (7)$$

The accuracy of the simulation is determined by the formula:

$$d_S=\max_n\{dY_n\}. \qquad (8)$$

Table 2

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

Response	Simulation error dY_n %	Response	Simulation error dY_n %
t_1	1.1	T_1	1.5
t_2	1.6	T_2	2.5
t_3	1.9	T_3	2.1
t_4	0.8	T_4	1.8
t_5	2.2	T_5	2.7
t_6	2.5	T_6	2.6
t_7	2.8	T_7	3.3
t_8	2.2	T_8	2.4

During the trial simulation experiment, it was established that the upper limit of the simulation error is equal to $d_{SM}=3.3$ % with permissible 5 %. Thus, the simulation error is insignificant for this study.

5. 4. Evaluation of modeling results

According to the reports obtained as a result of the simulation, the time for the preparatory work on the organization of the delivery of goods was determined depending on: four types of supply chains; enterprise sizes; organization of the enterprise's processes of exporting goods (Table 3).

As a result of modeling of supply chains of four types, the time of delivery of goods by enterprises along the routes Kyiv – Poznan, Kyiv – Berlin, Kyiv – Andorra was determined (Table 4).

Analysis of the simulation results shows that the fourth type of supply chain is the most effective. Its use when performing a foreign trade transaction will make it possible to reduce the duration of the delivery of goods by 9 % compared to the supply chain of the first type, by 6 % – of the second type, and by 4 % – of the third type. Involvement of consulting companies also reduces the duration of delivery of goods.

Table 3

Results of modeling the implementation of preparatory work on the organization of delivery of goods through supply chains

Types of logistics chain	The average value of the time of delivery of goods, h. (MEAN)±Standard deviation, h. (STD.DEV.)							
	Type of enterprises							
	Big		Medium		Small		Micro	
	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting
I	15.03±1.86	10.26±1.08	19.5±2.37	13.76±1.58	25.5±3.17	17±2.03	32.5±4.13	19.85±2.39
II	13.01±1.66	8.75±0.9	17.1±2.13	12.25±1.44	22±2.73	15±1.83	26.5±3.17	17.85±2.25
III	11.02±1.55	7.23±0.65	14.5±1.96	10.27±1.16	18.5±2.44	12.5±1.51	22.5±2.85	14.85±1.89
IV	9.01±1.06	7.51±0.83	11.05±1.36	8.75±1.02	13.5±1.72	10.03±1.2	16.5±2.09	11.35±1.42

Table 4

Supply chain delivery simulation results

The average value of the time of delivery of goods, h. (MEAN)±Standard deviation, h. (STD.DEV.)								
Types of logistics chain	Type of enterprises							
	Big		Medium		Small		Micro	
	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting
Kyiv – Poznan								
I	63±2.05	58.25±1.08	67.5±2.37	61.75±1.58	73.5±3.17	65±2.03	80.5±4.13	67.85±2.39
II	61±1.83	56.75±0.9	65±2.11	60.26±1.44	70±2.73	63±1.83	74.5±3.17	65.85±2.25
III	59±1.7	55.25±0.65	62.5±1.96	58.25±1.16	66.5±2.44	60.5±1.51	70.5±2.85	62.85±1.89
IV	57±1.17	55.5±0.83	59±1.36	56.75±1.02	61.5±1.72	58±1.2	64.5±2.09	59.35±1.42
Kyiv – Berlin								
I	72.41±2.23	67.66±1.29	76.91±2.84	71.16±1.9	82.91±3.8	74.41±2.44	89.91±4.96	77.26±2.87
II	70.41±1.99	66.16±1.07	74.42±2.53	69.66±1.73	79.41±3.27	72.41±2.2	83.9±3.8	75.27±2.7
III	68.41±1.85	64.66±0.78	71.93±2.35	67.67±1.39	75.9±2.92	69.91±1.81	79.91±3.41	72.26±2.27
IV	66.41±1.27	64.91±1	68.41±1.63	66.16±1.22	70.91±2.06	67.41±1.44	74±2.51	68.8±1.7
Kyiv – Andorra								
I	143.7±2.6	138.9±1.51	148.17±3.32	142.42±2.21	154.17±4.43	145.67±2.84	161.2±5.78	148.52±3.35
II	141.67±2.32	137.42±1.25	145.68±2.95	140.93±2.02	150.68±3.82	143.68±2.56	155.17±4.44	146.55±3.15
III	139.68±2.16	135.93±0.91	143.17±2.74	138.92±1.62	147.17±3.41	141.17±2.11	151.18±3.98	143.51±2.64
IV	137.67±1.48	136.17±1.16	139.67±1.9	137.4±1.42	142.2±2.41	138.7±1.68	145.2±2.93	140.02±1.98

The duration of the performance of their functional duties by each link of the logistics chain is ensured by the availability of the necessary resources to provide services without waiting in service queues and to eliminate errors related to professional activities. It is possible to ensure the optimal time characteristics of foreign trade operations by assessing the reliability of the functioning of a separate logistics chain and its links. Accordingly, this will make it possible to determine the influence of each of the links on the reliability of the processes in which they are involved.

The reliability of the supply chain is related to the timely performance of transport, logistics, and customs services for customers. Thus, the expediency of the study on the involvement of enterprises providing logistics consulting services in the process of formation of supply chains is confirmed. This will make it possible to assess the impact of choosing the most effective organization for cooperation, taking into account an expert approach to the analysis of the business entity's activities, and provide regulations for the performance of all types of work related to the execution of a foreign trade operation.

The essence of the method of statistical tests in relation to the study of reliability problems implies building a probabilistic analog of the system and obtaining various variants of implementations of the random process, which are processed using the methods of mathematical statistics. At the same time, the influence of random factors in the modeling process is taken into account by introducing elements of randomness by conducting draws. As an element of randomness, a generator of pseudo-random numbers is applied, which is used to simulate random processes. The simulation results are processed with a limited number of realizations of the random process. At the same time, the minimum amount of tests is determined from the condition of obtaining the specified accuracy and reliability. It took 100,800 hours of model time to ensure the specified accuracy of estimates of probabilistic characteristics by the method of statistical tests in GPSS.

The reliability (sustainability) of the supply chain and its links in the performance of preparatory work for the organization of the delivery of goods is defined as an assessment of the probability of timely execution of individual operations and the entire process as a whole (Table 5).

The reliability of supply chains of four types in the delivery of goods on the routes Kyiv – Poznan, Kyiv – Berlin, Kyiv – Andorra (Table 6) was also determined.

Table 5

Reliability of the logistics chain and its links in the performance of organizational and preparatory work

Types of logistics chain	Type of enterprise							
	Big		Medium		Small		Micro	
	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting
I	0.82	0.85	0.80	0.82	0.77	0.79	0.73	0.75
II	0.86	0.88	0.83	0.86	0.81	0.83	0.78	0.80
III	0.88	0.93	0.86	0.91	0.85	0.89	0.82	0.87
IV	0.93	0.95	0.90	0.93	0.89	0.91	0.87	0.90

Table 6

Reliability of the supply chain when delivering goods along routes

Types of logistics chain	Type of enterprise							
	Big		Medium		Small		Micro	
	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting	Manufacturing and trading enterprises	Logistics consulting
Kyiv – Poznan								
I	0.80	0.83	0.77	0.80	0.74	0.77	0.70	0.73
II	0.83	0.86	0.80	0.84	0.78	0.81	0.75	0.78
III	0.85	0.91	0.83	0.89	0.82	0.87	0.79	0.85
IV	0.90	0.93	0.87	0.91	0.86	0.89	0.84	0.87
Kyiv – Berlin								
I	0.79	0.83	0.76	0.79	0.73	0.76	0.69	0.72
II	0.82	0.85	0.79	0.83	0.77	0.80	0.74	0.77
III	0.84	0.90	0.82	0.88	0.81	0.85	0.78	0.83
IV	0.89	0.92	0.86	0.90	0.84	0.87	0.82	0.86
Kyiv – Andorra								
I	0.77	0.81	0.75	0.78	0.71	0.74	0.67	0.70
II	0.81	0.84	0.77	0.81	0.75	0.78	0.72	0.75
III	0.83	0.89	0.80	0.86	0.79	0.84	0.75	0.82
IV	0.87	0.91	0.84	0.88	0.82	0.85	0.80	0.84

The reliability of the supply chains of the first and second type in this case is low due to the unsatisfactory value of the reliability of its links since to ensure a sufficiently high level of reliability of the supply chain as a whole, it is necessary to ensure a sufficiently high level of reliability of each of its links.

The developed simulation model of the supply chain makes it possible to determine the probabilistic indicators of the supply chain, including the probability of meeting deadlines, as well as the reliability of the supply chain as a whole and its individual links. In addition, this SM makes it possible to determine the structure of the supply chain with the given reliability characteristics under certain restrictions, which are optimal according to the selected performance evaluation criteria.

6. Discussion of results of the development of a simulation model of delivery of goods in international road traffic

Our results testify to the effectiveness of the involvement of enterprises that provide logistics consulting services at the stage of forming supply chains (Table 1). This makes it possible to shorten the duration of the selection of intermediary organizations that will be involved in the execution of a foreign trade transaction. Specialists in logistics consulting can achieve such a result due to the speed of processing information available in specialized databases. An equally important aspect is expertise in the selection of subjects of foreign economic activity and assessment of their compliance with the needs of the customer regarding the delivery of goods. The obtained time characteristics indicate that the duration of preparatory work for the organization of goods delivery increases with the increase in the number of intermediary organizations that are part of the supply chain structure. Due to the need to agree on the terms of cooperation and make management decisions regarding its expediency. These results confirm the effectiveness of engaging in the delivery of goods in an international network of enterprises capable of providing the widest possible range of services. The duration of the delivery of goods according to the results of modeling shows that, under the condition of coordination of the carrier's actions, a significant number of organizations involved in the supply chain and their interdependent actions influence the time parameters of transportation.

The assessment of the reliability of the execution of preparatory work (Table 3) and the delivery of goods (Table 4) confirms that with an increase in the number of links in the supply chain, the probability of the occurrence of risks increases. Usually, they are associated with errors in professional activity and delays associated with a low level of coordination of actions of all involved organizations. In addition, as the transportation distance increases, delivery reliability indicators decrease, due to the risks that may arise on the route of the vehicle.

A significant achievement of our research is that it was possible to develop a simulation model for planning a foreign trade operation. It implies the possibility of the exporter to independently organize interaction with intermediary organizations or to involve companies that provide logistics consulting services.

It was possible to implement the simulation model in the GPSS World simulation automation package, which, unlike [2–5], makes it possible to study the process of export operations according to various types of supply chains. The simulation model provides for determining the duration and reliability of a foreign trade operation depending on the chosen form of interaction with intermediary organizations and the type of supply chain. Unlike other SMs, it takes into account the available resources and technical and operational indicators of the work of private enterprises of the transport and logistics complex and customs authorities.

A certain limitation of the simulation model is that it can only be applied to the delivery of goods along four types of supply chains in international road transport.

But even with the described shortcomings of SM, the execution of a foreign trade transaction will justify the following decisions for the exporter:

– the expediency of organizing a foreign trade operation on your own or with the involvement of enterprises that provide logistics consulting services;

– determine the duration and reliability of a foreign trade transaction, provided that a certain type of supply chain is selected.

Random number generators were used in the development of the simulation model. At the same time, SM itself has a probabilistic nature, which can be a source of imitation error. This technique provides the most accurate process modeling results that reflect the processes taking place in supply chains, provided that various intermediary organizations are included in their structure.

The significant limitations of this study when applied in practice are:

– impossibility of taking into account the quality and cost characteristics of product delivery in the model;

– additional financial costs that exporters will incur for paying for the services of consulting enterprises;

– there is no procedure for justifying the choice of a consulting company for cooperation;

– there is no procedure for justifying the choice of intermediary organizations and infrastructure facilities that are planned to be involved in the execution of a foreign trade transaction.

The main drawback of the study is that the developed simulation model does not take into account the organizational and technological processes related to the planning of foreign trade operations of specific types of goods, but is aimed only at ensuring the export of standard goods.

The development of this research has prospects in the following directions:

– the possibility of forming supply chains when delivering goods under different customs regimes;

– providing recommendations on foreign trade performance indicators not only to exporters but also to intermediary organizations that are part of the supply chain structure;

– development of supply chains to ensure the delivery of goods by various modes of transport by involving specialized public and private sector organizations as its links;

– taking into account the specifics of the organizational and technological support for the delivery of perishable, dangerous, oversized and prepackaged goods.

7. Conclusions

1. The model of goods delivery in international road transport has been formalized, subject to the involvement of enterprises providing logistics consulting services and the exporter's own forces in the organization of foreign trade operations. The essence of the model is the development of proposals for exporters regarding the choice of the optimal type of supply chain for foreign trade operations, taking into account the size of the enterprise and the customer's requirements regarding the duration and reliability of processes. The developed model provides for the possibility of performing a comparative analysis of the performance indicators of preparatory works and ensuring the delivery of goods by evaluating alternative solutions taking into account the individual conditions of cooperation with intermediary organizations.

2. A simulation model of goods delivery based on the application of various types of logistics chains using road transport has been developed. The proposed model provides an opportunity to analyze the characteristics of the formation of logistics chains of various types for large, medium, small, and micro enterprises, which will make it possible to choose the optimal option according to the criteria of duration and reliability of service. The developed model makes it possible to research and optimize the process of organizational and technological support of foreign trade operations according to various types of logistics chains. The structure of supply chains includes objects of customs and logistics infrastructure, such as warehouses, cargo customs complexes, checkpoints, and logistics centers that provide service exclusively to road carriers. The simulation model takes into account the characteristics of their activities since in practice a significant share of delivery delays is associated with restrictions in their work during a war.

3. The test included an adequacy check. To this end, the value of the *t*-statistic t_n was determined. The maximum value of t_n is 1.678 with its critical value of 1.85. Thus, it was established that the developed simulation model corresponds to the real conditions of the process under investigation.

4. During the trial simulation experiment, it was established that the upper limit of the simulation error is 3.3 %, which does not exceed permissible 5 %. In order to achieve estimates of probabilistic characteristics by the method of statistical tests in GPSS, it took 100,800 hours of model time.

The results of the simulation show that the application of the fourth type of supply chain is the most effective, as it involves at this stage the need to agree on the terms of cooperation with the minimum number of business entities. Its use in the execution of a foreign trade operation will make it possible to reduce the duration of the delivery of goods by an average of 9 % compared to the logistics chain of the first type, by 6 % – of the second type, and by 4 % – of the third type.

Indicators of the reliability of organizational measures to ensure the export of goods show that the effectiveness of the application of the fourth type of supply chain for all categories of enterprises provides the highest indicators of reliability in comparison with others. It should also be noted that consulting enterprises provide a process reliability indicator that is 5–8 % higher than manufacturing and trading enterprises.

The reliability of delivery decreases depending on the growth of the transportation distance, due to the risks that may arise during transportation. In general, reducing the number of links in the supply chain ensures the minimization of risks associated with their activities. Therefore, the reliability of delivery according to the fourth supply chain with the participation of a consulting company will make it possible to increase the reliability of a foreign trade operation by an average of 9 %.

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 and the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available in the main text of the manuscript.

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