This study investigates the process of organizing the work of a warehouse enterprise when servicing customers. The task set is to devise recommendations for planning the staffing of a warehouse enterprise, taking into account the duration of rendering services to customers.

A simulation model of the work of a warehouse enterprise when servicing customers has been built and implemented in the GPSS World simulation modeling automation package. The model involves determining the duration of warehouse service and determining the required number of personnel to enable the work of the business entity by areas of activity.

When constructing the model, the duration of the types of work performed at individual stages of service performed by the warehouse enterprise personnel when processing foreign trade cargo was taken into account. In addition, the model takes into account the probability of errors and delays in rendering warehouse services at each stage of the business entity's work, as well as the average delay time in the presence of errors. This can make it possible to determine the duration of additional employment of the enterprise personnel associated with the elimination of errors made in all types of work.

Applying the devised model in practice will allow owners of warehouse enterprises to organize and plan activities of the business entity when servicing customers. This will also make it possible to determine the duration of rendering warehouse services when performing foreign trade operations, taking into account the indicators of the efficiency of specialists.

At the same time, the probability of refusal to provide warehouse services to customers could decrease by 17% while the throughput capacity of the enterprise would increase by 22%

Keywords: warehouse enterprise, simulation model, logistics chain, road transportation, personnel management

UDC 656.135.073

DOI: 10.15587/1729-4061.2025.341456

CONSTRUCTION OF A SIMULATION MODEL OF THE WORK OF A WAREHOUSE ENTERPRISE AS A LINK IN THE LOGISTICS CHAIN

Ievgenii Lebid
PhD, Associate Professor
Department of Logistics and Project Management**

Nataliia Luzhanska
PhD, Associate Professor*

Iryna Lebid
PhD, Professor*

Alexander Mazurenko
Corresponding author
PhD, Associate Professor
Department of Transport Units
Ukrainian State University of Science and Technologies
Lazariana str., 2, Dnipro, Ukraine, 49010
E-mail: uamazurenko@gmail.com

Iryna Mykhailenko
PhD, Associate Professor
Department of Higher Mathematics,
Classical and Applied Mathematical Disciplines
Kharkiv National Automobile and Road University
Yaroslava Mudroho str., 25, Kharkiv, Ukraine, 61002

Svitlana Sharai
PhD, Associate Professor*
*Department of International
Transportation and Customs Control**
**National Transport University
Mykhaila Omelianovycha-Pavlenka str., 1, Kyiv, Ukraine, 01010

Received 10.07.2025
Received in revised form 22.09.2025
Accepted 30.09.2025
Published 31.10.2025

How to Cite: *Lebid, Ie., Luzhanska, N., Lebid, I., Mazurenko, A., Mykhailenko, I., Sharai, S. (2025). Construction of a simulation model of the work of a warehouse enterprise as a link in the logistics chain. Eastern-European Journal of Enterprise Technologies, 5 (3 (137)), 36–45. https://doi.org/10.15587/1729-4061.2025.341456*

1. Introduction

The quality of warehouse services has a significant impact on the efficiency of foreign trade operations since the process of preparing goods for transportation, including their packaging, labeling, assembly, and formation of cargo spaces, enables safety during transportation. One of the key indicators of the efficiency of warehouse services is the duration of work, which is a component of the delivery time of goods and has a significant impact on the overall delivery time.

It is advisable to use modern approaches to organizing the work of a warehouse enterprise, taking into account both internal potential and demand for services by customers. The material-technical and personnel support of a business entity form the basis for its competitiveness in the market. However, the quantitative and qualitative component of these aspects, combined with effective management strategies, makes it possible to render warehouse services with significant advantages compared to other organizations.

The operation of a warehouse enterprise, as an infrastructure facility, requires significant financial investments in its construction and operation, therefore it is advisable to involve customers in the service in order to reduce the payback period of this project. Depending on the speed of goods movement in the warehouse and the duration of service, customers can decide to establish cooperation or not to plan repeated service because of delays.

The duration of warehouse service rendering is affected by the number of administrative, managerial, and technical employees by type of work, their level of qualification, and ability to provide a high level of quality and reliability of services. In addition, practical experience of warehouse enterprises shows that the vast majority of service delays are associated with the presence of errors in the work of personnel and additional time spent on their elimination. Therefore, there is a need to develop software packages that could allow the management of a warehouse enterprise to assess the effectiveness of rendering services to customers and plan activities for future periods.

Scientific research on improving the organization and planning of warehouse enterprises is relevant for forming the competitiveness of a business entity and ensuring effective customer service. It is possible to achieve high efficiency indicators of the warehouse by optimizing internal production processes and external interaction with customers of services on the basis of a customer-oriented approach.

The practical implementation of such results will make it possible to plan the work of a warehouse enterprise taking into account the personalization of services, transparency of processes, speed and quality of customer service. In addition, it will be possible to determine the required number of warehouse personnel by areas of activity, the probability of service failure, as well as the throughput capacity of the infrastructure facility.

2. Literature review and problem statement

In [1], the application of RFID (Radio-Frequency Identification) technology in logistics processes is considered in order to increase the efficiency of inventory management. The proposed monitoring information system makes it possible to abandon manual operations, replacing them with computerized control in real time. The results of the research showed that RFID integration increases the efficiency of warehouse process management and can also serve as a basis for building inventory optimization models and improving procurement policies. The cited work can be used as a technical basis for a simulation model of individual technological operations of the warehouse but does not make it possible to study its operation from the point of view of the complete technological process of processing orders.

In [2], the use of a genetic algorithm is considered to optimize the storage of materials on rack positions according to the High-Runner Strategy method. The goal is to minimize the time required for picking. The reported procedure makes it possible to develop a software tool in the form of an optimization model that can be used for the needs of optimizing warehouse logistics processes in various types of production processes. This approach can be used to build a simulation model as a separate module for optimizing warehouse operations. However, it cannot be applied to study the operation of a warehouse as a specific technological process that involves processing an order from the moment it arrives at the warehouse to the moment it is shipped.

In [3], an innovative approach is proposed that integrates time series analysis with reinforcement learning to increase the accuracy of demand forecasting and optimize warehouse operations. A reinforcement learning modeling model is proposed to optimize inventory management policies, taking into account order frequency, order fulfillment times, and storage restrictions. The integration of time series analysis with reinforcement learning and hyperparameter optimization made it possible to dynamically respond to changing market conditions, optimizing both demand forecasting and warehouse management. However, this approach almost does not touch on the specificity of warehouse operation in the sense of processing each individual order. In addition, it cannot be used to study the impact of possible errors and delays in rendering warehouse services on the duration of order processing.

In [4], discrete-event modeling of events is used to analyze warehouse operations with a special emphasis on unloading. The simulation model works on the basis of using historical data collected in the company; to assess the efficiency of warehouses, such performance indicators as resource utilization, capacity utilization, and downtime cost are determined. The work focuses on how service time, site capacity, and queue organization affect throughput and costs. However, this approach does not take into account the possibility of studying the impact of errors and delays in the process of rendering warehouse services on the total processing time of applications.

In [5], the planning of warehouse tasks in the context of tight order fulfillment deadlines is investigated. A data-driven decision-making methodology is proposed that combines priority task planning with the use of flow shop models traditionally used in production but adapted for warehouse operations. To assess the effectiveness of various priority rules, stochastic modeling is used that takes into account the uncertainty of real conditions. The results showed that the critical ratio rule based on the real-time status of the task queue provides the fastest execution and is optimal for scenarios with high product cost and significant labor costs. The cited work reveals the importance of task management in the warehouse but does not take into account that at each stage of service there may be some delays due to errors in processing requests and the need for repeated actions with them.

In [6], a warehouse workflow model is reported, which integrates a management methodology based on changes in the state of dispatchers and logistics equipment, the distinction of task scenarios, and the behavior of dispatchers. The workflow model serves as a conceptual abstraction of a parallel warehouse planning system, while the integrated management methodology models the entire decision-making process of dispatchers to solve potential blocking problems during task execution. This model details the internal processes of warehouse management, but it does not take into account the impact of various delays in servicing requests and the possibility of determining the required number of personnel to enable uninterrupted operation.

In [7], the use of computer modeling methods for optimizing warehouse location is considered, which is an important component of effective supply chain management. The study uses a detailed simulation model built using FlexSim software. The results of the study show that virtual simulation modeling significantly improves decision-making processes, leads to significant time and cost savings, contributing to increased supply chain productivity and operational efficiency. The work is intended to study and optimize the location of warehouses in the logistics chain but does not make it possible to study the order processing process and the impact of the human factor on it.

In [8], the supply chain is represented as a complex logistics system analyzed in the AnyLogistix environment, which includes production centers, warehouses, distribution centers, suppliers, retailers, or trade networks. An analysis of the elements of the supply chain management system and their interaction according to the assigned agents was carried out, namely a supply procurement agent, a logistics agent, a transport agent, a planning agent, a supply agent, a dispatcher agent, etc. The work covers a wide range of interactions in the supply chain, but a specific warehouse simulation model is considered superficially and without emphasis on its internal operations.

In [9], the integration of discrete-event modeling (DES) and the concept of digital twins in the context of logistics and warehouse activities are considered. The authors analyze architectural approaches to combining the model and the physical object. The simulation model combines the DES core for modeling flows and loading resources with an interface for receiving real-time data (sensors, RFID) and a mechanism for "live" calibration of the model as a digital twin. However, the work cannot be used to study and determine the duration of warehouse service requests and determine the required number of personnel to enable functioning.

In [10], a two-stage approach is proposed for modeling, which combines time series analysis for demand forecasting with reinforcement learning (RL). This could make it possible to optimize the inventory management policy and resource allocation in integrated production and warehouse systems. This approach is valuable for forecasting and inventory management, but it does not make it possible to study the internal processes of order servicing that occur directly at the warehouse.

In [11], the design of a real-time inventory control system based on RFID is described: architecture, data, algorithms, and implementation results. If a sensor infrastructure is planned or exists in the real environment, the model should provide the ability to import and synchronize states with the "physical" warehouse as a digital twin. The study demonstrates a practical tool for calibrating warehouse simulation models but does not take into account the warehouse function in relation to transport and production flows.

In [12], a simulation model (SM) of goods delivery in international road transport is given. The model is focused on optimizing organizational and technological processes of both individual links and the entire supply chain. The study takes into account the time characteristics of preparatory work in interaction with institutions and organizations, as well as direct service to the exporter. The work focuses on the transport supply chain but the warehouse as a separate object of simulation modeling is not detailed, which limits its application for the study of internal processes.

The use of simulation modeling in the study of a warehouse enterprise operation as a link in the logistics chain could make it possible to reproduce all organizational, managerial, and production processes that are performed when servicing customers. The direct process of forming a logistics chain requires the involvement of a business entity capable of ensuring a high level of quality and reliability of service provision in its structure.

Therefore, there is a need to define performance indicators for a separate warehouse enterprise at the current point in time to justify the feasibility of cooperation with it for future periods. It is simulation modeling that will make it possible to fully take into account not only the time characteristics of all types of work but also the impact of errors and delays on the duration of customer service. An important aspect of using a simulation model in the work of warehouse enterprises is the ability to determine the optimal number of specialists in areas of activity that will provide service for the specified flow of orders.

Thus, building and implementing such a model has significant practical significance for managing the internal processes of the warehouse, and could also be used to determine its effectiveness as a link in the logistics chain.

3. The aim and objectives of the study

The purpose of our work is to model the process of rendering warehouse services for organizing international cargo transportation, taking into account the time characteristics of the work of warehouse enterprise specialists at all studied stages of service. This will make it possible:

– to provide recommendations to the management of warehouse enterprises regarding the efficiency of customer service;

– to plan the duration of warehouse service, taking into account errors in work and delays at each stage of work;

– to plan the staff number of warehouse enterprise specialists required for customer service.

To achieve this aim, the following objectives were accomplished:

– to formalize the model of the warehouse enterprise's work when servicing customers;

– to evaluate the results of warehouse enterprise modeling when servicing customers.

4. The study materials and methods

The object of our study is the process of organizing the work of a warehouse enterprise when servicing customers.

The hypothesis of the study assumes that the use of SM of the work of a warehouse enterprise when organizing and planning cooperation with customers of services will make it possible to optimize administrative, managerial, and technical employees by areas of activity. It will make it possible to study the current state and planning of the work of a warehouse enterprise for future periods, taking into account the demand for services and the duration of all types of work when servicing an order.

For the effective operation of a warehouse enterprise, it is advisable to determine the duration of customer service at different stages of cooperation, which is performed by specialized specialists. Each of them can perform their duties with or without errors. Accordingly, the proposed SM, for the completeness of the study of these aspects, provides for the consideration of the probability of errors and delays at each stage, as well as the average delay time when errors occur. This will make it possible to more accurately determine the duration of order service and its impact on the total duration of a foreign trade operation. In addition, it will be possible to form a qualitative and quantitative composition of the enterprise's staff, taking into account the indicators of their work efficiency.

The proposed simulation model was implemented in the GPSS World simulation automation package [13]. The GPSS World environment makes it possible to automatically obtain results based on the statistical testing method.

5. Determining the optimal number of warehouse managers when servicing customers

5. 1. Formalization of the warehouse operation model

To build a mathematical model of the warehouse operation, we introduce the following notations:

$A=\{a_1, a_2, ..., a_m\}$ is a set of known model parameters;

$X=\{x_1, x_2, ..., x_k\}$ is a set of controlled model parameters;

$U = \{u_1, u_2, \ldots, u_r\}$ is a set of random model parameters;

$Z = \{z_1, z_2, \ldots, z_p\}$ is a set of initial model parameters that determine the purpose of building a simulation model for the process of rendering warehouse services in organizing international cargo transportation.

In this case, Z is a function of A, X, and U, that is

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

From customers of warehouse services in the organization of international cargo transportation, applications for service are received.

Thus, factors X of the model are the number of applications α_i received for rendering warehouse services per unit of time.

Two strategies in the operation of a warehouse enterprise are considered when service can be provided:

– in the presence of errors in service;

– without errors in service.

Processing of an application for warehouse service from customers in the organization of international cargo transportation is the execution of operations W_{ij} according to stages ST_i given in Table 1. The duration of each operation is considered as a random variable with a given distribution law.

Initial parameters Z of the model, which are determined for both strategies of operation of transport enterprises, are:

– average performance indicators of the enterprise;

– duration of warehouse service t_j, min;

– duration of waiting in the queue for warehouse service w_k, min;

– length of the queue for warehouse service η_k, order;

– share of applications that are serviced without downtime in the queue ν_k, %;

– load factor of managers ψ_k;

– average number of employed managers ρ_k;

– probability of service failure q_k;

– throughput A, order/month;

– optimal number of managers for warehouse service n_k^*;

– reduction of warehouse service duration Δt_j, %;

– increase in throughput ΔA, %;

– reduction of probability of service failure Δq, %.

Each of the stages under study is characterized by a number of factors.

Factors A of the model are:

– the number of managers to service a separate flow of applications n_k;

– the duration of a separate stage of service $m_{ij} \pm \sigma_{ij}$, min.;

– the average delay time when errors occur $\mu_{ij} \pm \varepsilon_{ij}$, min.

Factors U of the model are:

– the probability of errors at stage γ_{ij};

– the probability of delays at stage λ_{ij}.

Accordingly, the management of the enterprise faces the issue of planning the personnel of the enterprise, capable of organizing warehouse service in the shortest possible time in the absence of errors and delays at all stages. It is also important to minimize refusals in rendering services through the employment of specialists or the lack of free vehicles.

Table 1

Types of activities in organizing warehouse services for customers

Activity ID	Activity type	Executor (position)
ST1	Stage 1. Receiving goods into the warehouse	
W11	Acceptance of an application for placing goods in a warehouse (from a client or logistics department)	Warehouse administrator
W12	Checking documents for goods (invoice, invoice, certificates)	Warehouse administrator
W13	Inspection of goods for compliance with documents (quantity, packaging, quality)	Warehouse operator
W14	Receipt of goods in a warehouse (registration in the accounting system)	Warehouse operator
W15	Determination of the place of storage of goods in a warehouse	Warehouse logistician
ST2	Stage 2. Placing the goods in the warehouse	
W21	Transporting goods to the storage location (using special equipment)	Warehouse operator
W22	Placing goods on shelves/storage locations according to the system	Warehouse operator
W23	Marking the storage location (label, barcode)	Warehouse operator
W24	Updating the accounting system with information on the placement of goods	Warehouse administrator
ST3	Stage 3. Preparation for release of goods from the warehouse	
W31	Acceptance of a request for the issuance of goods (from the client or the logistics department)	Warehouse administrator
W32	Checking the goods for readiness for issuance (packaging, quantity)	Warehouse operator
W33	Preparation of accompanying documents for the issuance of goods (invoice, invoice)	Warehouse administrator
W34	Assembling goods for issuance	Warehouse operator
ST4	Stage 4. Release of goods from the warehouse	
W41	Loading goods into a vehicle (if special equipment is required)	Warehouse operator, driver
W42	Checking driver or client documents for receiving goods	Warehouse administrator
W43	Signing documents for issuing goods (invoice, transfer certificate)	Warehouse administrator
W44	Updating the accounting system after issuing goods	Warehouse administrator
ST5	Stage 5. Analysis and completion of the process	
W51	Checking the remaining goods in the warehouse after issue	Warehouse logistician
W52	Archiving documents on the receipt and issue of goods	Warehouse administrator
W53	Analysis of the effectiveness of the placement and release of goods	Warehouse manager

The initial characteristics Y of the model, which are determined for both strategies of operation of warehouse enterprises, are:

– average performance indicators of the enterprise;
– duration of warehouse service t_j, min;
– waiting time in the queue for warehouse service w_k, min;
– length of the queue for warehouse service η_k, order;
– share of applications that are serviced without downtime in the queue ν_k, %;
– load factor of managers ψ_k;
– average number of employed managers ρ_k;
– probability of service failure q_k;
– throughput A, order/month.

As efficiency indicators Z, which determine the goals of modeling, the responses of model Y and the following indicators are considered:

– optimal number of managers for warehouse maintenance n_k^*;
– reduction of the duration of warehouse maintenance Δt_j, %;
– increase in throughput capacity ΔA, %;
– reduction of the probability of failure in maintenance Δq, %.

To model the process of rendering warehouse services in organizing international cargo transportation, taking into account the time characteristics of the work of warehouse enterprise specialists at the studied stages of maintenance, it is proposed to use the theory of mass service.

The flow chart of work performed in organizing warehouse maintenance is shown in Fig. 1.

An example of the text in a simulation model for the functioning of a warehouse enterprise when servicing customers in GPSS World is shown in Fig. 2.

SM should reflect the work of a warehouse enterprise in servicing customers. Therefore, for its further use, the adequacy of the model to a real warehouse enterprise was checked.

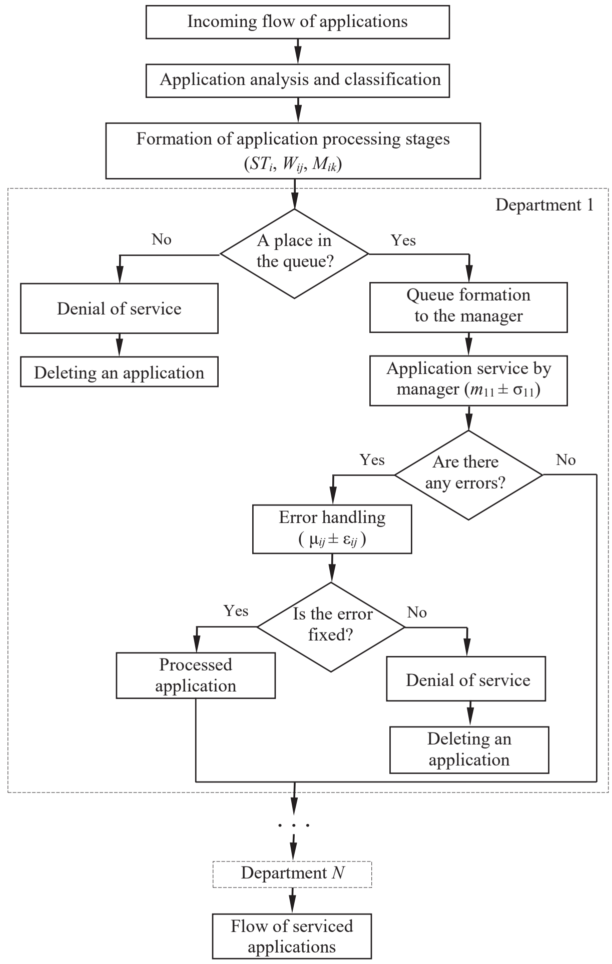
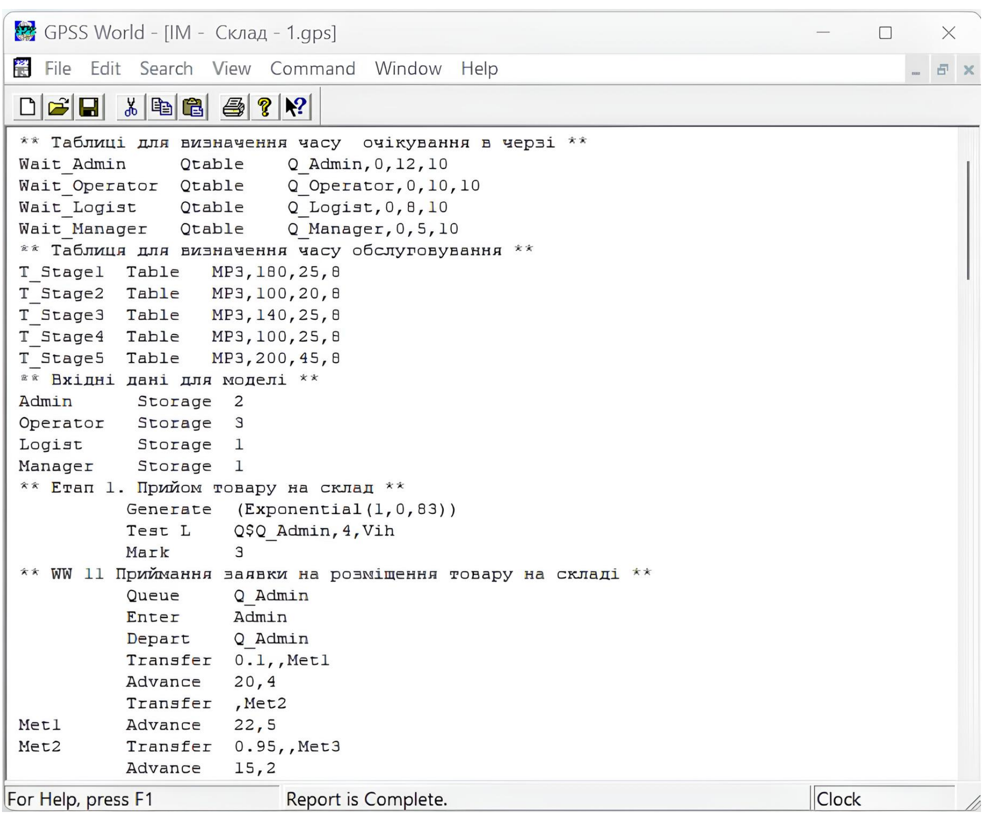


Fig. 1. Flowchart of modeling the work execution process



```
** Таблиці для визначення часу  очікування в черзі **
Wait_Admin     Qtable    Q_Admin,0,12,10
Wait_Operator  Qtable    Q_Operator,0,10,10
Wait_Logist    Qtable    Q_Logist,0,8,10
Wait_Manager   Qtable    Q_Manager,0,5,10
** Таблиця для визначення часу обслуговування **
T_Stage1  Table   MP3,180,25,8
T_Stage2  Table   MP3,100,20,8
T_Stage3  Table   MP3,140,25,8
T_Stage4  Table   MP3,100,25,8
T_Stage5  Table   MP3,200,45,8
** Вхідні дані для моделі **
Admin       Storage  2
Operator    Storage  3
Logist      Storage  1
Manager     Storage  1
** Етап 1. Прийом товару на склад **
          Generate  (Exponential(1,0,83))
          Test L    Q$Q_Admin,4,Vih
          Mark      3
** WW 11 Приймання заявки на розміщення товару на складі **
          Queue     Q_Admin
          Enter     Admin
          Depart    Q_Admin
          Transfer  0.1,,Met1
          Advance   20,4
          Transfer  ,Met2
Met1      Advance   22,5
Met2      Transfer  0.95,,Met3
          Advance   15,2
```


Fig. 2. Fragment of the program listing in GPSS World

To this end, the hypothesis of the proximity of the average values of the service duration and the duration of downtime in the queue was tested according to the warehouse enterprise $\overline{Y}^*$ data and the simulation results $\overline{Y}$, obtained on the SM built. $N_1 = 5$ experiments were conducted on a real object, and a sample of values was formed $\{Y_i^*\}, i = \overline{1,5}$. Using the simulation model, $N_2 = 5$ experiments were conducted; samples of values $\{Y_i\}, i = \overline{1,5}$. were obtained based on the model's responses.

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

Table 2

Verifying the adequacy of the simulation model

Re-sponse	Sample component values					$\overline{Y}_n, \overline{Y}_n^*$	$\overline{D}_n, \overline{D}_n^*$	D_{an}	t_n
	$j=1$	$j=2$	$j=3$	$j=4$	$j=5$				
t_{1j}	184	172	191	178	199	184.8	112.7	101	0.661
t_{1j}^*	190	165	180	185	183	180.6	89.3		
t_{2j}	117	121	113	128	111	118	46	69.25	0.760
t_{2j}^*	125	115	110	120	100	114	92.5		
t_{3j}	194	191	203	197	199	196.8	21.2	64.35	1.222
t_{3j}^*	190	205	195	210	215	203	107.5		
t_{4j}	124	152	133	156	149	142.8	186.7	147.1	0.548
t_{4j}^*	135	145	140	160	155	147	107.5		
t_{5j}	148	131	142	153	133	141.4	89.3	104.65	1.020
t_{5j}^*	135	150	145	165	145	148	120		
w_{1j}	33	26	29	37	28	30.6	19.3	15.25	0.648
w_{1j}^*	30	28	32	35	36	32.2	11.2		
w_{2j}	8	11	13	9	12	10.6	4.3	4.75	1.016
w_{2j}^*	6	10	12	10	8	9.2	5.2		
w_{3j}	10	7	12	17	14	12	14.5	13.9	1.018
w_{3j}^*	8	5	10	15	10	9.6	13.3		
w_{4j}	5	6	8	11	8	7.6	5.3	7.05	0.715
w_{4j}^*	3	5	10	9	5	6.4	8.8		

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

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

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

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

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

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

Values E_n and D_{an} are independent statistics, so the t-statistic can be used

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

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

5. 2. Evaluating the results of modeling a warehouse enterprise when servicing customers

As a result of modeling, the following statistics were obtained for queues and devices (Fig. 3).

The results of modeling the organization of warehouse service in the presence of errors in the work of warehouse enterprise specialists and without errors at all stages are given in Table 3.

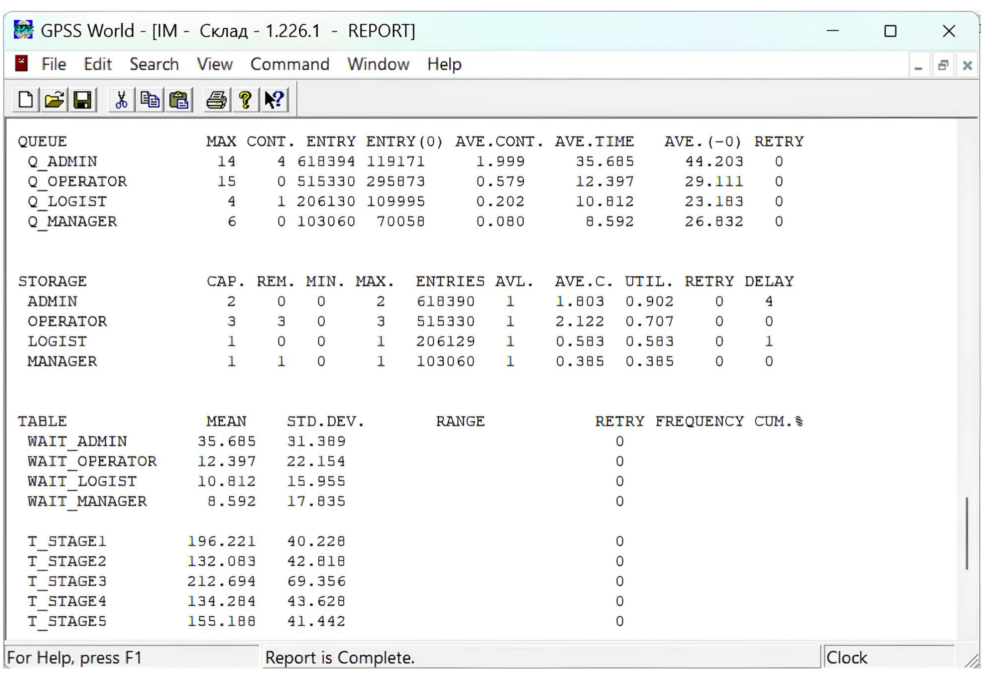


Fig. 3. Results of warehouse service organization modeling in GPSS World

Table 3

Results of simulation of average service time with and without errors

Service stages	Presence of errors		No errors	
	Average service time, min (MEAN)	Standard deviation, min (STD.DEV.)	Average service time, min (MEAN)	Standard deviation, min (STD.DEV.)
Stage 1. Receiving goods into the warehouse, t_1	196.2	40.2	184.6	36.7
Stage 2. Placing the goods in the warehouse, t_2	132.1	42.8	117.2	37.8
Stage 1–Stage 2. Receiving and placing goods in the warehouse	328.3	69.0	301.8	57.4
Stage 3. Preparation for the release of goods from the warehouse, t_3	212.7	69.4	194.7	60.6
Stage 4. Release of goods from the warehouse, t_4	134.3	43.6	124.1	38.5
Stage 3–Stage 4. Preparation and release of goods from the warehouse	347.0	99.4	318.8	84.5
Analysis and completion of the process, t_5	155.2	41.4	148.1	38.9
Stage 1–Stage 5. Warehouse maintenance	830.5	127.3	768.7	115.3

According to the data from the reports obtained as a result of modeling the work of a warehouse enterprise in servicing customers, the main indicators of the modeling results were determined and the duration of downtime in service queues was calculated (Table 4).

Analysis of our modeling results reveals that the "bottleneck" in the process of processing applications is the number of administrators, the increase of which will make it possible to improve the throughput capacity of the warehouse enterprise and reduce the time of servicing customers. With an increase in the number of administrators and operators, the following results of modeling the organization of warehouse service were obtained in the presence of errors in the work of warehouse enterprise specialists and without errors at all stages (Tables 5, 6).

Thus, an increase in the number of administrators and operators per person leads to the following results:

– the duration of warehouse maintenance in the presence of errors in the work of warehouse specialists was reduced by 19.5%, and in the case of maintenance without errors at all stages – by 18.9%;

– the probability of service failure decreased by 17%;

– throughput increased by 22%.

Table 4

Simulation results with and without errors in the work of warehouse specialists

Key modeling indicator	Administrator		Operator		Logistician		Head	
	error ("+" – present; "–" – absent)							
	+	–	+	–	+	–	+	–
Average queue idle time w_k, min	35.7	33.0	12.4	8.5	10.8	10.4	8.6	7.9
Average queue length, η_k, order	2.0	1.9	0.6	0.4	0.2	0.2	0.1	0.1
The share of applications served without downtime in the queue, ν_k, %	19.27	20.10	57.41	62.96	53.36	53.58	67.98	68.70
Duration of downtime in the queue, LT_k	71.4	62.7	7.44	3.4	2.16	2.08	0.86	0.79
Number of managers, n_k	2	2	3	3	1	1	1	1
Managers' workload, ψ_k	0.90	0.89	0.71	0.68	0.58	0.58	0.39	0.39
The average number of managers employed, ρ_k	1.80	1.79	2.12	2.04	0.58	0.58	0.39	0.39
Probability of denial of service, q_k	0.22	0.21	–					
Throughput, A, order/month	94.3	95.5	–					

Table 5

Results of simulating average service t ime with and without errors

Service stage	Presence of errors		No errors	
	Average service time, min (MEAN)	Standard deviation, min (STD.DEV.)	Average service time, min (MEAN)	Standard deviation, min (STD.DEV.)
Stage 1. Receiving goods into the warehouse, t_1	185.2	39.4	174.6	37.1
Stage 2. Placing the goods in the warehouse, t_2	100.3	24.9	88.7	22.0
Stage 1–Stage 2. Receiving and placing goods in the warehouse	285.5	54.3	263.3	49.1
Stage 3. Preparation for the release of goods from the warehouse, t_3	147.9	40.1	136.9	34.3
Stage 4. Release of goods from the warehouse, t_4	100.1	26.3	93.6	23.2
Stage 3–Stage 4. Preparation and release of goods from the warehouse	248.0	56.4	230.5	49.5
Stage 5. Analysis and completion of the process, t_5	135.2	38.1	129.6	36.1
Stage 1–Stage 5. Warehouse maintenance	668.7	118.8	623.4	102.7

Table 6

Simulation results with and without errors in the work of warehouse specialists

Key modeling indicator	Administrator		Operator		Logistician		Head	
	error ("+" – present; "–" – absent)							
	+	–	+	–	+	–	+	–
Average queue idle time w_k, min	10.3	9.0	5.8	3.9	22.6	21.2	8.9	8.6
Average queue length, η_k, order	0.7	0.6	0.3	0.2	0.5	0.5	0.1	0.1
The share of applications served without downtime in the queue, ν_k, %	50.13	53.07	70.44	75.9	34.54	35.09	64.25	64.51
Duration of downtime in the queue, LT_k	10.3	9.0	5.8	3.9	22.6	21.2	8.9	8.6
Number of managers, n_k	3	3	4	4	1	1	1	1
Managers' workload, ψ_k	0.74	0.72	0.65	0.61	0.72	0.70	0.48	0.47
The average number of managers employed, ρ_k	2.23	2.16	2.61	2.45	0.72	0.70	0.48	0.47
Probability of denial of service, q_k	0.05	0.04	–					
Throughput, A, order/month	120.8	121.0	–					

6. Discussion of results based on modeling the work of a warehouse enterprise

The issue of the effectiveness of foreign trade operations depends on the quality of intermediary services provided by all involved organizations. Among them, the work of warehouse enterprises should be highlighted, which are involved at the stage of forming a batch of goods for an international voyage. All types of work performed by these infrastructure facilities are provided by specialized specialists, taking into account the physical and chemical, commodity and transport properties of the cargo. Each of the service stages is characterized by a different duration of execution, the probability of errors and the time required to eliminate shortcomings in the work. Thus, depending on the time of implementation of the internal processes of the warehouse enterprise, the total duration of the foreign trade operation will be formed. As practical experience shows, significant advantages in cooperation are given to enterprises that are able to provide optimal time, cost and quality indicators of service among others operating on the market. Therefore, it is advisable to introduce into the activities of intermediary organizations, including warehouse enterprises, software complexes capable of investigating all processes occurring during customer service. This will make it possible to identify existing shortcomings in the work and take timely measures to eliminate them. Researching the efficiency indicators of a separate warehouse enterprise depends on such factors as:

– area of the warehouse enterprise;

– number of administrative, managerial, and technical personnel of the enterprise;

– demand for services among customers;

– list of services and types of work that can be performed when servicing customers;

– specificity of cargoes provided for service;

– availability of means of automation and mechanization of warehouse work;

– duration of service for individual types of work;

– probability of errors in service;

– duration of error elimination in service.

The modeling results allow us to provide recommendations to a separate warehouse enterprise, taking into account its material, technical, and personnel support. This will make it possible to investigate the strengths and weaknesses of the infrastructure facility, determine the main indicators of customer service efficiency, and plan for future periods.

A significant advantage of a separate warehouse enterprise is the ability to effectively use existing resources and justify the feasibility of implementing optimization solutions. The use of the developed software package makes it possible to analyze significant data sets for different periods of warehouse operation. Unlike [1], the simulation model built makes it possible to consider the warehouse enterprise as a link in the logistics chain and take into account the time characteristics of warehouse service as an element of the duration of a foreign trade operation.

The proposed advancement, unlike [2], considers both the internal processes of the warehouse enterprise and the impact of changes in demand for services among customers on the throughput capacity of the infrastructure facility and staff employment. In addition, our SM, in comparison with [3], considers not only internal warehouse processes but also the specificity of the warehouse's interaction with transport and production links.

The proposed SM, in contrast to [4], will allow customers and other intermediary organizations to determine the feasibility of cooperation with individual infrastructure facilities based on the analysis of their performance indicators as a link in the logistics chain. In turn, the owner of the warehouse enterprise will have the opportunity for constant analysis in order to form the competitiveness of the organization.

The use of our SM, in comparison with [5, 6], provides the opportunity to analyze the impact of the intensity of service requests from customers and the duration of processing a batch of goods in the warehouse. In contrast to [7], the presented model focuses on detailing the technological process of the infrastructure facility and its efficiency in order to establish cooperation in the formation of logistics chains. In addition, it considers the impact of the enterprise's staffing on the results of its activities.

A significant advantage of the proposed development, compared to [8], is the significant detailing of the stages of warehouse maintenance, all types of work that accompany them, and the indication of the executors of a separate process. This makes it possible not only to carry out a generalized analysis but also to study individual elements of the warehouse functioning.

Our SM, unlike [9], considers a set of organizational and managerial, technical, and technological measures that take place in the warehouse. This makes it possible to take into account the versatile aspects and characteristics of the infrastructure facility. A rather important element of the SM built, compared to [10, 11], is the consideration of the influence of external factors on the internal processes that take place in the warehouse. This provides the opportunity to study the readiness of the warehouse's material-technical and personnel support to the growth of demand for services and the possibility of effective interaction with intermediary organizations.

Unlike [12], our SM considers warehouse maintenance when delivering goods in international traffic. The effective organization of warehouse and transport services will enable a high level of quality of foreign trade operations.

Our results from simulating the operation of a warehouse enterprise make it possible to determine the required number of personnel of the enterprise and their workload coefficient, the probability of service failure, as well as the throughput capacity of the infrastructure facility. In addition, it will be possible to consider two strategies for the operation of the warehouse, namely, with errors in service and without errors.

In turn, the presented list of stages and types of work performed by a warehouse enterprise when servicing customers (Table 1) makes it possible to form the structure, characteristics, and performers of all necessary operations. As a result of field tests, the adequacy of the model was checked (Table 2), which indicates the feasibility of its application in the analysis of the operation of warehouse enterprises. The average time for servicing customers of a warehouse enterprise with errors and without errors (Table 3) by service stages increases by 62 minutes.

A study of the performance indicators of warehouse enterprise specialists (Table 4) indicates the need to increase the number of administrators who will provide an increase in the throughput capacity of the enterprise at a significant level of the probability of service failures. With an increase in the number of administrators, we can observe a reduction in service time (Table 5) and an increase in the value of the main modeling indicators (Table 6).

The SM built involves determining the optimal number of warehouse enterprise employees by areas of activity depending on the demand for services among customers.

The advantages of our study are the possibility of implementing management decisions in the planning of the warehouse enterprise's work, taking into account the available personnel and material and technical support of the enterprise involved in performing various types of work.

The defined characteristics of the warehouse enterprise's work when performing foreign trade operations indicate significant differences in the duration of various stages of service in the presence of errors in work and without errors. At the same time, the main share of errors is observed in the work of administrators and is associated with order processing and coordination of service details.

The main limitations of SM include the fact that it does not take into account the specific characteristics of cargoes that can affect the duration of organizational and technological processes.

The disadvantages of SM are that it provides for the possibility of studying the work of a warehouse enterprise when servicing general cargoes and does not consider the process of servicing perishable and groupage consignments of goods.

Future research has prospects in the following areas:

– the possibility of studying the efficiency indicators of a warehouse enterprise for perishable and groupage cargoes;

– construction of SM for the work of a customs warehouse;

– construction of SM for the work of a temporary storage warehouse;

– construction of SM for the work of an open and closed type warehouse enterprise;

– construction of SM for the work of a warehouse enterprise when transporting goods by air, rail, or sea.

7. Conclusions

1. We have formalized a model of the warehouse enterprise's operation in performing foreign trade operations. The proposed formalization involves studying the efficiency indicators of the warehouse enterprise's work in servicing customers. The main stages of service and the list of works that characterize them have been defined. The condition is considered that each type of work can be performed with errors in service and without errors. In addition, the probability of errors and delays in performing individual types of work, as well as the average delay time when errors occur, are taken into account. The proposed formalization provides for the possibility of studying the efficiency indicators of the enterprise's specialists by areas of activity, which makes it possible to optimize measures to be taken depending on the current needs of the organization. A significant advantage of this measure will be the ability to manage the enterprise's processes taking into account the flow of service orders. The feasibility of this formalization is aimed at the possibility of planning the duration of warehouse service, which has an impact on the total duration of the foreign trade operation.

2. The results of our simulation of a warehouse enterprise in servicing customers have been evaluated, which involved determining the efficiency indicators of its activities in the presence of errors in servicing and without errors for various types of work. In addition, the simulation model built makes it possible to determine the full-time staff of the enterprise by functional distribution.

The results of our simulation modeling indicate that when planning the staffing of the warehouse enterprise in accordance with the existing flow of orders, the following indicators change if there are errors in servicing:

– the duration of service decreased by 19.48% (with the key role belonging to stage No. 3 – preparation for the release of goods from the warehouse; the time for its execution decreased by 30.46%);

– the average number of employed managers increased by 23.51%;

– the load factor of managers decreased by 17.77%;

– the average downtime in the queue decreased by 71.14% (administrator) and by 53.23 (operator);

– the share of applications that are serviced without downtime in the queue increased by 30.86% (administrator) and by 13.3% (operator);

– the probability of failure decreased by 77.27%;

– the throughput increased by 28.1%.

In turn, in the absence of errors in service, the modeling results will be reflected as follows:

– the duration of service will decrease by 18.9% (with stage No. 3 also playing a key role, the execution time of which was reduced by 29.68%);

– the load factor of managers will decrease by 19.1%;

– the average number of employed managers will increase by 20.41%;

– the probability of failure will decrease by 80.95%;

– the throughput will increase by 26.7%.

Thus, the implementation of the proposed simulation model will allow warehouse enterprises to optimize the qualitative and quantitative indicators of personnel performance. This will ensure a high level of competitiveness of the enterprise and will provide an opportunity to expand the activities of the infrastructure facility taking into account demand.

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. Hosseini, M., Chalil Madathil, S., Khasawneh, M. T. (2025). Reinforcement learning-based simulation optimization for an integrated manufacturing-warehouse system: a two-stage approach. Expert Systems with Applications, 290, 128259. https://doi.org/10.1016/j.eswa.2025.128259
2. Anoop, K. P., Panicker, V. V., Das, A. S., Abhishek, T., Vadlamani, P. S., Akhil, U. S. (2020). Simulation modelling and analysis of warehouse operations in a food grain supply chain. International Journal of Logistics Systems and Management, 37 (4), 465. https://doi.org/10.1504/ijlsm.2020.111853
3. Erlangga, S. B., Yunita, A., Satriana, S. R. (2022). Development of Automatic Real Time Inventory Monitoring System using RFID Technology in Warehouse. JOIV: International Journal on Informatics Visualization, 6 (3), 636. https://doi.org/10.30630/joiv.6.3.1231
4. Kim, T. Y. (2020). Improving warehouse responsiveness by job priority management: A European distribution centre field study. Computers & Industrial Engineering, 139, 105564. https://doi.org/10.1016/j.cie.2018.12.011
5. Fedorko, G., Molnár, V., Mikušová, N. (2020). The Use of a Simulation Model for High-Runner Strategy Implementation in Warehouse Logistics. Sustainability, 12 (23), 9818. https://doi.org/10.3390/su12239818
6. Zeng, Y., Li, W., Li, C. (2024). A dynamic simulation framework based on hybrid modeling paradigm for parallel scheduling systems in warehouses. Simulation Modelling Practice and Theory, 133, 102921. https://doi.org/10.1016/j.simpat.2024.102921
7. Krynke, M. (2024). Virtual Simulation Modeling as a Key Element of Warehouse Location Optimization Strategy. Management Systems in Production Engineering, 32 (3), 339–344. https://doi.org/10.2478/mspe-2024-0032
8. Dimitrov, R. (2024). Simulation Modelling of Multi-Agent Logistics Model in AnyLogistix Environment. Science, Engineering and Education, 9 (1), 75–82. https://doi.org/10.59957/see.v9.i1.2024.10
9. Agalianos, K., Ponis, S. T., Aretoulaki, E., Plakas, G., Efthymiou, O. (2020). Discrete Event Simulation and Digital Twins: Review and Challenges for Logistics. Procedia Manufacturing, 51, 1636–1641. https://doi.org/10.1016/j.promfg.2020.10.228
10. Hosseini, M., Chalil Madathil, S., Khasawneh, M. T. (2025). Reinforcement learning-based simulation optimization for an integrated manufacturing-warehouse system: a two-stage approach. Expert Systems with Applications, 290, 128259. https://doi.org/10.1016/j.eswa.2025.128259
11. Erlangga, S. B., Yunita, A., Satriana, S. R. (2022). Development of Automatic Real Time Inventory Monitoring System using RFID Technology in Warehouse. JOIV : International Journal on Informatics Visualization, 6 (3), 636. https://doi.org/10.30630/joiv.6.3.1231
12. 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
13. GPSS World Reference Manual (20021). Holly Springs NC, 305. Available at: https://athena.ecs.csus.edu/~mitchell/csc148/gpssW/Reference%20Manual/reference_manual.htm