Simulation modeling as a means of organizing technological processes in warehouse logistics

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Abstract. The results of creating a simulation model of technological processes in a warehouse are revealed in this study. The relevance of the study is justified by the significant increase in the share of online trade in the Russian economy and, as a consequence, the increase in demand for warehouse and logistics services. This requires modernization of technological processes in the warehouse to increase the speed of sorting and shipping of goods, as well as their high-quality storage. The use of structural analysis and synthesis methods allowed establishing all the key objects and characteristics of business processes in the warehouse. Based on this, a model of the behavior of objects was created and, using simulation methods, a digital twin of technological processes was developed, which allowed performing experiments to develop a concept for the operational management of relevant processes.

1 Introduction

In Russia, during the period 2018–2022, a rapid increase in interest in online shopping and the active development of marketplaces were noted. This reflected the general trends in the global e-commerce and logistics market. According to a report prepared by BusinesStat, during the determined period, specific dynamics were observed among marketplaces among all consumer segments of fulfillment in Russia. The volume of this segment had increased more than 14 times [https://businesstat.ru/news/fulfillment]. Sanctions introduced in 2022 led to the departure of foreign fulfillment operators, however, their sales shares were replaced by domestic companies without having a significant impact on the fulfillment market in Russia.

The development of the online trading sector has increased requirements for the level and quality of goods delivery. This in turn has significantly increased the demand for warehousing and logistics services. Modernization of existing warehouse facilities and optimization of operations are priorities for most companies, since the construction of a new space is a long and costly process, which subsequently requires the organization of logistics services [1].

When preparing a plan for modernizing warehouse facilities, traditional methods such as expanding the staff and increasing warehouse space are most often used. In some cases,

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specialists may be involved in developing measures for improving the warehouse processes [2]. The key feature of this approach is the use of the accumulated experience of the involved specialist. In modern realities, this might be vulnerable, since the external environment is dynamically changing, and testing of developed concepts is performed on real objects. Under such conditions, it is impossible to test several different concepts simultaneously.

The solution to the problem might be the use of simulation modeling. Using this approach, a computer model of a warehouse can be created with the organization of all processes arising in warehouse logistics [3]. At the same time, the consequences of the introduction of different concepts can be evaluated at any time interval.

Therefore, the study was aimed at optimizing logistics processes in warehouses. The processes of organizing and accepting goods from the supplier, placing them in storage cells, sorting goods according to the established storage rules, assembling and placing orders, organizing and loading orders to senders were the object of the study.

The theoretical significance of the study lay in obtaining a formal model of the processes occurring in the warehouse. The practical significance of the study consisted in obtaining the results that allowed developing rules ensuring efficient logistics of goods within a warehouse as well as a set of measures for the operational management of processes in order to reduce downtime for forklifts and other equipment, distribute the load and reduce order processing time.

2 Materials and methods

Development of a simulation model reflecting all aspects of the problem area is necessary for obtaining a detailed description of all objects and processes that exist in the corresponding area. Herewith, the nature of the subject area does not matter. As the authors of the studies related to the simulation modeling note, it is necessary to establish the structure of the object. This approach can be found in the studies related to the modeling of transport infrastructure [4-6]. In order to implement this approach, the study used the method of structural analysis and synthesis which allowed establishing all the structural elements of the object of the study and the features of their interaction. In addition, all potential external influences on these objects had been identified.

For the functioning of the system and the corresponding model, a set of data and rules of the appropriate format is required. And it makes no difference which sphere this approach is applied to. It can be used, for example, in the development of information systems in the social sphere [7], education [8] and services [9, 10]. In addition to using the method of analysis, the methods of systematization, grouping and other methods being part of the methods of mathematical and statistical analysis are also necessary for obtaining such data.

Having obtained a set of all the necessary data and rules, an appropriate model is created using simulation methods. For this purpose, specialized software was applied allowing to formalize the data obtained. The models being the basis of the simulation model and including, for example, the model of object state transitions, were created by means of these particular tools and graphical methods. An analysis of the performed studies has shown that researchers often create state diagrams to demonstrate and subsequently use the results obtained in simulation modeling [4, 6, 11].

3 Results

Based on the analysis results, the following technological processes are performed in the warehouse:
1. Receiving of goods. As part of this process, the goods are unloaded from the vehicle and placed in a temporary storage area. In the appropriate area, the quantity and quality of goods are verified according to documents from the supplier. In addition, the receipt of the goods is documented (the delivery identification data are put into the information database).

2. Putaway. This process provides for the movement of goods throughout the warehouse for the organization of their storage, subsequent transportation or shipment to the customer. Putaway is performed in a designated area and provides for the possibility of additional packaging of certain items of goods in a single container.

3. Slotting of goods. After the sorting and packaging process, the goods are placed on storage racks using a forklift. Slots are selected in such a way as to provide a unified storage system for products.

4. Shipment of goods. The goods are shipped in a specially designated area, delivery to which is performed using a forklift from the goods storage positions. Before loading into a vehicle, the goods may be additionally packaged. During the above processes the goods are processed, their quality and completeness are monitored.

Organizing logistics within a warehouse is a key component allowing to organize the movement of forklifts, thereby reducing the time it takes to move cargo. In order to create a simulation model based on the warehouse layout, a model of forklift movement was developed (Fig. 1).

Fig. 1. Network of routes through the warehouse in a simulation model.

In the area where the racks are located there are at least two lines allowing for the simultaneous movement of loaders in different directions, which increases the channel capacity.

Loaders or goods control specialists have access to the loading, unloading and sorting areas.

In addition to the route network, the simulation model is based on behavior models of key objects. State diagrams have been developed to illustrate the behavior of forklifts during the implementation of the following processes: unloading and putaway (Fig. 2) as well as sorting of goods before shipment (Fig. 3).
In order to visualize the obtained results of the functioning of the simulation model using specialized software, a three-dimensional model has been developed. This model corresponded to all processes in the warehouse and reflected all the quantitative and qualitative characteristics of all processes being the object of this study. Figs. 4-7 demonstrate fragments of three-dimensional visualization of the simulation model.

**Fig. 4.** Packaging area in the simulation model.

**Fig. 5.** Loading and unloading area in the simulation model.

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**4 Discussion**

Simulation of technological processes in a warehouse is a complex process that requires a clear formulation of the requirements for the tasks performed. As the results of performed studies demonstrate, much depends on the formulation of the requirements that must be taken into account when organizing the efficient work of the warehouse [2, 3]. Logistic optimization of warehouse operation includes designing technological warehouse processes as a complex system [1].

During this study, technological warehouse processes were analyzed, key objects and rules for their interaction were obtained, qualitative and quantitative characteristics were established, and formal models of the behavior of structured objects were developed. All this became the basis of a simulation model that corresponded to all key aspects of the subject area. The results obtained are reliable, since general scientific research methods were used and similar results were obtained in the other studies related to the development of simulation models [4-6, 12].

It should be noted that the results obtained in this study correspond to the concept of lean production [13-15].

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**5 Conclusion**

Simulation modeling is a tool that allows creating and using a digital twin of a warehouse. By means of applying such a digital twin, it is possible to conduct many experiments related to the creation of peak loads, test the efficiency of changing the storage positions of goods, etc.
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Computer graphics were simplified (for example, there was no painting of the walls, the location of the goods relative to the forklift did not match) in order to reduce the load on the computing processes of specialized software and a computer. All this does not affect the simulation principle of technological processes.

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increasing or decreasing the number of forklifts, using loaders in the process of sorting goods, etc. When performing such experiments, it is not necessary to stop real technological processes.

The results obtained in this study can be used in the activities of a business analyst who must interpret the results during simulation modeling and make decisions on the operational control of technological processes, develop concepts for their modernization, etc. In this way, the concept of lean manufacturing can be implemented.

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