WAREHOUSES AND CARGO TERMINALS IN SUPPLY CHAINS

Abstract
Warehouses and cargo terminals of transport sphere, which play an important role in the logistics of delivery systems, are considered within the context of the theory of warehouse systems. According to the theory, they are created in sites of the interactions between different areas of transport and production systems, various modes of transport and do not serve for storage of cargo alone, but rather are utilized for the conversion of cargo flows. Doing so allows responding the purpose of subsequent transportation and the usage of cargo in the most efficient way. Those storage facilities ensure the formation of the particular parameters of traffic flows that are tailored to the need of different markets, including goods, works, and services, in agreement with the principles of business logistics. The formalization of the of warehouse system functioning, provided the application of the graph or matrix of transition probabilities, is based on the main stages of analyzing or projecting a warehouse as a complex stochastic technical system that is presented in details.

Keywords: warehouses, cargo terminal, supply chains, theory of warehouse systems.

Warehouse facilities are crucial objects in supply chains. Their importance, however, is underestimated, and they are considered just as some miscellaneous objects for cargo storage. Very often cargo inventory at warehouses is the single parameter that is estimated when the total supply chain is researched. Meanwhile, other warehouse characteristics, such as storage technology and equipment, methods of cargo processing are vital for the whole supply chain optimization. Determination of inventory at various warehouses in a supply chain is not enough for its optimization.

Modern mechanized and automatic warehouses are very complicated technical objects. They are equipped with specific complex equipment (e.g., racking systems of various performance, automatic stackers and forklift trucks, automatic conveyor systems, and automated guided vehicles (AGV), means of robotics, palletizers, computers and on-line electronic data exchange systems, etc.). Besides, they display stochastic sort of activity. In every case of reconstruction or building some new warehouse, there may be many options, with different parameters and economic characteristics (Malikov, 1981; Malikov, 1986; Malikov, 2003).

Therefore, the most fruitful approach for the modern warehouses creation is to represent them as complicated stochastic systems, following the theory of warehouse systems (TWS), which had been worked out by the author of this article in the last 30 years. The general cybernetic theory of systems (GCTS)
was applied as a foundation for this theory. Central concepts of the TWS are considered further. The basic point of TWS is the purpose of creation and functioning of warehouses in a logistic chain (Figure 1).

![Diagram of a supply chain with components: transport T_i and warehouses W_j, a transport link between two facilities F_1 and F_2, and a scheme of warehouse W interaction with inbound transport T_i and outbound one T_o.]

Commonly or widespread opinion is that warehouses are created for storage some inventory in supply chains. However, there are many different types of warehouses in supply chains, and not all of them are providing this function. It is known indeed that no product or merchandise is manufactured just for storage. They should move to the consumers.

Any supply chain always consists of two sorts of elements: warehouses and transport links between them (Figure 1a). So, the material flows do not go just from one partner to another one, but flow between warehouses in a logistic chain. Analyses of logistic systems shows that any well-organized logistic chain and every transportation process starts and terminates at some warehouses (W_1, W_2 in Figure 1b). A warehouse always interacts with two types of transport – arriving T_i and dispatching T_o (Figure 1c).

Material flow, however, is characterized not only by single parameter – the total amount of cargo, transporting per a year. Leading other features of a material flow are as follows: volume of transport batches; number of different items of cargo in transport batches; type and characteristics of transport tare and packing freight; type and features of freight transport units (pallets, containers), in which cargo arrives and dispatches; technology and conditions of cargo
transportation; and regularity and conformity of transport batches arrival and dispatching (Malikov, 2005; Malikov, 2009).

Comparison of these characteristics of inbound $A_j$ and outbound $B_j$ flows of goods displays that they may differ from each other (Fig. 1c). Therefore, the original purpose of warehouses in supply chains is changing or transforming some of the flow parameters during cargo transportation along the supply chain from one partner to another one. For example, the amount of the transport batches can be changed, if goods come to warehouses with big batches in heavy-duty long distance trucks, and deliver to customers with small batches in small local trucks. At the same time, a number of goods items, in transport batches, can lessen. In the warehouse of a logistic center, goods can be unpacked and stored in some other or even special tare, pallets or containers. In that case, characteristics of packing and freight transport units can be transformed as well, when goods are retrieved from the storage area, and transport batches are prepared for the delivering to customers.

The finished product warehouse of the factory has to transform the products flow so as it would conform to all requirements of customers. That will be its purpose, i.e. to adapt parameters of the goods flow outgoing from the warehouse for the best following transportation of the goods. The storage of materials and unfinished components of a factory transforms characteristics of the inbound material flow so that they would match to the technological processing at the plant. In the same manner, freight terminal at a railway station or marine port, a warehouse of semi-finished components at the factory, etc. can be considered.

Warehouses are organized in the points of transport networks, where the transformation of material flows is necessary. Going through different transport systems, material flow on its way from manufacturers to customers adopts particular characteristics of these systems. So, it can be declared that warehouses of various types are created in logistic chains in the points of interaction of different transport and industrial systems with an objective of material flow transformation for the best subsequent transportation and/or using goods. Temporary storage and handling cargo at the warehouses are just some of its processing operations, fulfilled for changing of parameters of the material flows with its equipment and technology.

Therefore, the target of warehouses in supply chains is not just keeping some stock, but the transformation of the parameters of material flows so as they would come to the end consumers in accordance with principle of business logistics MQTPQC-P, i.e. needed merchandise (M), in needed quantity (Q), in needed time (T), in needed place (P), of required quality (Q), in needed condition (C), and by affordable competitive price (P). Thus, just-in-time is not a general principle, but the only local requirement to deliver merchandise in proper time (e.g., the concept of 7R).
Transformation of material flow in a warehouse should be fulfilled with the most efficient way, i.e. with the least spending of 6 primary resources, which are present in the real natural environment: space, time, materials, energy, labor, and money. At the same time, processing merchandise, warehouses create its additional value because they follow principle mentioned above. Therefore, warehouses fulfill the general objective of the whole supply chain, because the material flow parameters are created there.

While the material flow moves along the supply chain from one storage to another, every warehouse changes parameters of this flow (according to its assignment), adding some value to the merchandise. For example, these may be points of different modes of transport interaction. Therefore, the first and the most significant problem when the supply chain is analyzed or created is the determination of locations of warehouses in the chain of cargo delivery and their capacity. However, this is not the end of optimization, as is sometimes perceived.

According to TWS, a warehouse should be analyzed, in case of the reconstruction of existing warehouse, and created, if new warehouse is erected, as technical and economic system, consisting of the following elements or technological areas: unloading dock, area of temporary storage of arrived cargoes before haulage them to the main warehouse; area of reception and sorting of arrived cargo; main stock area; subsystem of picking and retrieval of dispatched goods; area of temporary storage and preparation of products for shipping from the warehouse; loading dock; inner warehouse transport; and warehouse management system (WMS). Each of aforementioned components of a warehouse system has its own technology, equipment, and purpose of functioning. But there is one common system objective, which all the components operate for. That is known as a synergetic effect in the general theory of systems.

The storage area in the warehouse facilities of different types should be projected and operated professionally and efficiently so as the warehouse space was used more completely. There is a great variety of the methods of merchandise storage that are characterized by the type of the storage method (e.g., stack, racking or conveyor); type and parameters of stock keep unit (SKU), racking structures and handling (e.g., stacker) equipment. As analyses show, there may be a number of hundreds of storage methods as combinations of these factors for any specific original conditions. The coefficient of the storage area volume utilization $k$ is the most important index of storage method efficiency that may fluctuate from 0.12 up to 0.8.

While the functioning of the warehouse system interacts with the environment, which consists of some outside systems (e.g., vendors, transport, consumers, forwarders and so on), this interaction with surrounding systems should be planned in order that it would help the warehouse system to reach its main objective of material flow transformation. Practically, this interaction of
the warehouse system with the environmental systems represents mutual transferring material and informational flows, which make the warehouse to pass upon this influence from one its state to another. In the processes of interacting with environmental systems, the warehouse transfers from one state to other ones, which are characterized by types and amount of technological operations to be carried out at the moment, cargo to be stored, delivered to and from the warehouse, picked, sorted, business of employees, forklift trucks, cranes, conveyors, racking, and other warehouse equipment being used. Functioning of warehouse system as the procedure of transitions from one condition to other ones can be represented in a view of graph or matrix of transition probabilities. This method of formalization of warehouse system functioning can be used for its calculations, simulation, research, and optimization (Malikov and Malkovich, 1989).

For doing so, the main stages of analyzing or projecting a warehouse as a complex stochastic technical system should be considered: objective setting (it should be single); selection and determination of elements of technological areas and warehouse structure, as various connections between system elements; analyzing of system functioning (including its simulation); consideration of system interaction with surrounding environment; consideration of results of the warehouse system performance, and operation. It is interesting to point out that this general methodology can be used while creating or analyzing any other transformation of technical or social system, which receives a flow of some objects with one set of parameters, processes it through its structure, and gives them out with other values of parameters (Malikov, 2008).

References