Features of development of an agricultural warehouse digital twin

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Abstract. The article presents the main results of the development of simulation model of agricultural warehouse. Such a model is a digital twin of the real object that reflects all qualitative and quantitative characteristics of objects and included processes. The creation of such digital twin is necessary to assess the effectiveness of the organization of storage, packing, loading and unloading of agricultural products. The relevance of the research lies in the specificity of realization of the above processes due to their intensity depending on the season, microclimatic conditions of the premises, fragility, and short life of products. As a result of using the methods of structural analysis, simulation modeling and graphical method, all key objects and processes of the subject area are established and characterized, behavioral models and three-dimensional visualization of the simulation model are developed.

Keywords. Simulation modeling, structural analysis, business processes, management, logistics

1 Introduction

Finished agricultural products are the end result of the production cycle and can be intended both for sale and for the internal needs of the farm [1]. In this regard, it can be prepared for transportation between farm warehouses, transportation to a processing plant or points of sale, as well as left for a certain period of storage. It should be noted that the time the above processes are implemented is significantly influenced by the seasonality of production, the territorial location of farm facilities and external receiving points, as well as the heterogeneity of production [1]. All this implies uneven use of any material resources and money during the year and requires coordination in time which is more careful than in other industries [2].

Regardless of the branch of agriculture, warehouse logistics consists in the formation of batches of products with the exclusion of shortages and surpluses, even distribution of workers and machinery on the time of work, packing and assembly of products for efficient storage and movement, competent placement in storage and warehousing of all objects [3].

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For the agricultural industry, the volume of the listed processes increases seasonally. For example, it is associated with harvesting or preparation for sowing crops.

As domestic and foreign researchers note in their works, digital transformation is required for effective realization of warehouse processes [4-6]. With the help of digital technologies, it is possible to quickly react and manage a large number of warehouse units with fewer errors [5]. The use of digital twins of a real physical object allows simulating its behavior in real time to evaluate the effectiveness of proposed changes in warehouse logistics.

Thus, the research objective is to create a digital twin to realize the smart warehouse concept. The object of the study is a farmhouse warehouse for agricultural crops. The subject of the study is the processes of shipment, loading, packing, sorting and storage of products.

Theoretical significance of the study lies in the formalization of warehouse logistics processes, setting their qualitative and quantitative characteristics. This is necessary to create a concept of effective production development, labor management and control of the environment of warehousing and cargo flows. Thus, the practical significance of the study is substantiated.

2 Materials and methods

Simulation modeling methods were used to create a digital twin. As researchers note in their works, such methods allow formalizing an object or processes of any subject area (e.g., transport, urban planning) [7, 8].

Full-fledged use of simulation modeling methods is possible only if there are formalized input parameters (what is used in the processes of the subject area) and established rules of interaction between objects and their corresponding processes [9, 10]. It became possible to establish the listed parameters using the method of structural analysis, gradually decomposing, and establishing the necessary connections. The method of direct assessment was used to clarify the individual values of the indicators, which made it possible to obtain data in real time from the installed sensors in the warehouse premises.

Graphical methods were applied to visualize the obtained results [7, 9]. They were used to create diagrams of process realization and a three-dimensional version of the simulation model, based on which scenarios of event forecasting were built.

3 Results

For the efficiency of the processes of an agricultural storage facility, all areas must be functionally separated. There are areas for receiving goods for storage, a picking and shipping area, a processing and sorting area, and a storage area divided into sections depending on climatic conditions. There are certain requirements for each zone, which ensure not only the organization of complex processes, but also the safety of products.

The total incoming (Qinput) and outgoing (Qoutput) flows represent the volumes of various cargoes passing through the warehouse during some minimum period t. The difference between these flows (considering the cargoes that were already on the premises) is defined as the daily stock of the warehouse R:

\[ R = R(t) + Q_{\text{input}} - Q_{\text{output}}. \]

To organize uninterrupted operation of the warehouse, the following condition must be met:
where \( R_{\text{min}} \) – is the minimum allowable volume of products at the beginning of the minimum storage period \( t \);

\( W \) – constant volume of premises.

If the conditions \( R \leq R_{\text{min}} \) or \( R > W \) are violated during any situation, a warehouse failure occurs. The parameter \( R \) is random and its value is influenced by random volumes \( Q_{\text{input}} \) and \( Q_{\text{output}} \), due to random flows of offers and orders, by competing factors and seasonality [11].

In addition to defining the zones in the warehouse, the structural analysis established the key entities involved in the processes:

- technologists who control the safety of products, climatic conditions in the warehouse, receiving and shipping of products;
- workers who perform packing of products;
- automatic loaders – technical means controlled by workers and carrying out the processes of lifting, moving, unloading, loading, storing pallets and other goods;
- conveyor loader – technical means that allows transferring solid substances (e.g. seeds, vegetables, fruits) and packaged products with minimal use of human resource.

Figure 1 shows the developed simulation model based on the production processes of the warehouse.

![Two-dimensional simulation model of warehouse processes](image)

**Fig. 1.** Two-dimensional simulation model of warehouse processes.

State diagrams were developed for each group of objects of the subject area identified during the structural analysis based on the mathematical model and the results of structural analysis. Such diagrams allowed establishing and visualizing the states in which the objects are located when implementing the processes. Fig. 2 shows fragments of the developed state diagrams for automatic loaders involved in the processes of unloading and loading of road transport, placement of cargo in the sorting zone and storage locations in the warehouse.

The behavior of objects in the simulation model is demonstrated in a three-dimensional model, namely the processes of placing packaged products on racks for temporary storage are visualized (Fig. 3), the processes of packing products in the sorting zone before placement on racks or shipment (Fig. 4) and the processes of loading packaged products (Fig. 5).
Fig. 2. Fragment of the state diagram of automatic loaders in the realization of processes in the warehouse.

Fig. 3. Fragment of the three-dimensional simulation model of the process of placing packaged products on racks for temporary storage.

Fig. 4. Fragment of the three-dimensional simulation model of the products packing process in the sorting zone.

Fig. 5. Fragment of a three-dimensional simulation model of the packaged products loading process.
The obtained simulation model is a digital twin of the real object. Scenarios of object behavior and changes in warehouse processes are built based on it. It is required to constantly update the indicators of the main objects such as the number and weight of cargoes, climatic conditions, and other indicators to accurately predict changes. For this purpose, sensors measuring temperature, weight, humidity and light level, cameras are used to implement computer vision technologies for $Q_{\text{input}}$ and $Q_{\text{output}}$ estimation.

4 Discussion

Creating a digital twin of a real object consisting of multiple interacting objects is a complex process that requires the integrated use of structural analysis, parametric and simulation modeling techniques [3, 7]. The works of researchers engaged in simulation modeling of different processes establish all qualitative and quantitative characteristics of objects of the subject area, as well as the rules of interaction between processes and potential external influences that can be exerted on them [8-10]. The same results were obtained during the conducted research.

Scenarios allowing to predict changes in the behavior of objects with a certain accuracy are created based on the simulation model [3, 5, 8]. In the works of domestic and foreign researchers it is noted that those are possible when the quantitative and qualitative characteristics of objects change [2, 10]. In the conducted study creation of scenarios is possible based on real indicators that come from the real object and are associated with the corresponding objects of the digital twin. This allows not only forecasting changes over a given time interval, but also making appropriate operational management decisions based on the obtained forecast. As noted in the works of researchers who automate business processes, such results can be used to create expert systems that allow not only real-time monitoring of changes in objects and processes in the warehouse, but also receiving recommendations for making managerial decisions [12, 13].

The use of digital twins is also possible in the training of specialists of the relevant industry. It provides a mean to form practice-oriented tasks in educational programs to assess the practical skills of specialists [14]. When using digital twins in this case, consumables are saved and it is possible to assess the consequences of the actions taken.

5 Conclusion

The active development of digital technologies, the rising employee salary costs, increasing costs of warehouse logistics, the departure of foreign companies – all this has brought significant changes in the supply chain of raw materials and goods, in the organization and implementation of warehouse processes. For warehouse logistics to be effective, it is necessary to change approaches to the organization and automation of the relevant processes.

Creating a digital twin that simulates warehouse logistics processes is an effective way to select optimal parameters and management technologies. This is achieved by repeatedly playing scenarios of object behavior on a computer model with successive changes in quantitative or qualitative characteristics. The digital twin visually demonstrates the processes in different areas of the warehouse, which allows evaluating the effectiveness of control actions and developing a unified concept of management of processes and resources of the warehouse.

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