Journal homepage: https://itce.vn.ua/en

Information Technologies and Computer Engineering **Vol. 23, No. 2. 2026**

Article's History: Received: 25.12.2025 Revised: 04.05.2026
Accepted: 25.06.2026 Published: 03.08.2026

ISSN 1999-9941; e-ISSN 2078-6387
UDC 004.94:658.7:004.42
DOI: 10.31649/vitce/2.2026.162

3D modelling of warehouse logistics in FlexSim software: Optimisation of logistics processes and resource management

Evheniy Slipenkyy*

Master of Science, Senior Lecturer
National University of Water Management and Nature Management
33028, 11 Soborna Str., Rivne, Ukraine
https://orcid.org/0009-0001-7538-9642

Abstract. The purpose of the study was to theoretically substantiate the potential of FlexSim software for three-dimensional modelling of warehouse logistics, improving warehouse processes, and providing analytical support for resource management in warehouse logistics systems. The study was theoretical and analytical in nature and was based on the systematisation of structural components of the composition, areas of three-dimensional modelling, FlexSim functionality, and resource balancing methods. The results showed that a warehouse should be viewed not as a static space for storing goods, but as a process-based system in which goods receipt, identification, storage, replenishment of picking zones, order picking, internal transport, packaging, dispatch, and stock control form a single operational chain. It was established that the three-dimensional model in FlexSim should combine the physical components of the warehouse – zones, racks, routes, workstations, equipment, conveyors, and automated vehicles – with logical components: queues, buffers, routing rules, service priorities and resource usage modes. Systematisation of 3D modelling areas has shown that optimisation of warehouse processes was formed at the spatial, process, and resource levels. The spatial level was estimated through average storage capacity utilisation ⩾90% and peak capacity utilisation ⩾100%; process level through time from product acceptance to placement <3.5 h, internal order processing cycle <3.36 h, and full order processing cycle <6 h; resource level through selection and shipment performance ⩾70 order lines/man-hour, overtime share <1.88%, average waiting time, maximum queue length, and resource utilisation level. The practical significance of the study is to form an integral conceptual model that is valuable for logistics managers, warehouse managers, and supply chain analysts, as it allows them to pre-identify bottlenecks, queues, downtime, resource imbalances, and risks of disrupting the rhythm of warehouse operations

Keywords: material flows; operational chain; throughput; bottlenecks; order acquisition

Introduction

During the period of active development of e-commerce, automation of warehouse operations, and digitalisation of supply chains in 2020-2026, warehouse logistics functioned in conditions of increasing intensity of material flows, complication of the order structure, increasing requirements for the speed of acquisition, and the need for rational use of warehouse space, personnel, and transport and technical resources. In such circumstances, conventional warehouse planning methods based only on static calculations or descriptive patterns of product movement no longer provide sufficient accuracy to assess the actual behaviour of the warehouse system. Of particular relevance is three-dimensional (3D) simulation modelling, which allows reproducing the warehouse as a dynamic system of interaction of zones of reception, storage, acquisition, packaging, shipment, intra-warehouse transport, employees, equipment, and information flows. In this context, flexible simulation (FlexSim) software is considered as a tool for building virtual models of warehouse systems, which allows theoretically substantiating the possibilities of optimising logistics processes without interfering with the real warehouse infrastructure.

Suggested Citation:
Slipenkyy, E. (2026). 3D modelling of warehouse logistics in FlexSim software: Optimisation of logistics processes and resource management. *Information Technologies and Computer Engineering*, 23(2), 162-177. doi: 10.31649/vitce/2.2026.162.

*Corresponding author (*evhenslipenkyy@outlook.com*)

In the study by K. Kolesnyk *et al.* (2023), simulation modelling of warehouse operations of a transport company is considered as a means of reproducing the movement of goods, interaction of warehouse zones, and estimation of time parameters of service. The advantage of this study was the applied focus of modelling on identifying bottlenecks in transport and warehouse interaction, but the research is mainly focused on a separate operational context and did not form a generalised model of using 3D modelling for integrated management of warehouse resources. I. Berezhniak *et al.* (2025) used modelling to improve the efficiency of service centre warehouse processes. The value of this approach consisted in considering the warehouse as a sequence of interrelated operations; however, the researchers' focus is limited to a specific organisational system, and the issue of generalising modelling parameters for different types of warehouse logistics structures has not been analysed in detail. F. Coelho *et al.* (2020) considered a simulation solution support tool for internal logistics in the context of creating a digital twin. The researchers focused on transferring the analysis of production and logistics processes to a virtual environment, which is important for the development of digital modelling of logistics systems. The main focus of the study was aimed at the concept of a digital double and decision support, while the specifics of building a 3D warehouse model, in particular, the relationship between storage zones, acquisition, transport routes, queues, and resource loading, did not act as an independent subject of analysis. P. Grznár *et al.* (2021) considered the optimisation of warehouse sorting using a genetic algorithm. The study demonstrated the potential of algorithmic methods for improving individual warehouse operations, but its subject was limited to the task of sorting, so it did not fully reveal the issues of complex 3D modelling of a warehouse as a storage system, moving, picking, inventory management, and resource balancing.

F. Kallat *et al.* (2021) considered automatic repository generation for component synthesis of warehouse simulation models. A strong aspect of this work was the representation of the warehouse system through a set of repetitive components that can be used to create simulation models. However, the emphasis is mainly on the component structure and automation of model development, while the management interpretation of modelling results, assessment of resource imbalances, and the relationship between the 3D representation of the composition and performance indicators require further theoretical generalisation. A systematic review by S. Abid & F.Z. Mhada (2021) analysed simulation and optimisation methods in the context of reverse logistics. The significance of this review was to systematise approaches to combining simulation and optimisation, but the subject area of work is not focused directly on warehouse logistics, and therefore the issue of spatial 3D modelling of warehouse zones, routes, queues, and resources was revealed only indirectly. The issue of designing automated warehouse systems is covered in the paper B.Y. Ekren (2020), where multi-criteria optimisation of Autonomous Vehicle Storage and Retrieval system (AVS/RS) – warehouse is associated with simultaneous consideration of performance, storage structure, technical resources, and operational constraints. This study was important for understanding automated warehouse systems, but its focus is on a specialised type of warehouse, so the results do not fully cover mixed warehouse systems in which personnel, loading equipment, conveyors, automated vehicles, manual picking zones, and information routing rules interact simultaneously. The study by S. Winkelhaus *et al.* (2022) modelled a hybrid order acquisition system that combines manual labour and autonomous selection tools. The advantage of this work was the review of hybridisation of warehouse operations, but the analysis is mainly focused on the acquisition process, while other components of warehouse logistics – acceptance, placement, replenishment of selection zones, packaging, shipment and inventory control – were not considered as a single integrated model.

The study by Y. Li *et al.* (2022) considered order acquisition efficiency in e-commerce as one of the key factors for warehouse logistics productivity. The researchers systematised approaches to order picking and showed the importance of the product selection stage for the speed of order execution, accuracy of operations, and overall performance of the warehouse. The study was mainly of a process-operational nature and did not reveal the issue of building a complete virtual warehouse model, in which acquisition is associated with the planning of storage areas, intra-warehouse transportation, loading of personnel, and inventory management. The study by G. Gao *et al.* (2022) used integration of placement system planning with simulation to design and evaluate production and logistics planning. The study demonstrated the importance of combining spatial planning and simulation analysis, but its main context is related to production systems, and not to warehouse logistics as a separate object of 3D modelling.

The combined analysis of scientific sources showed that 3D simulation modelling has become one of the key tools for warehouse logistics research, as it allowed combining spatial visualisation, process description, scenario analysis, and resource assessment. Unlike static warehouse diagrams, FlexSim's 3D model can display the dynamics of product movement, queues, downtime, staff loading, equipment usage, changes in order intensity, and the impact of organisational decisions on productivity. Simultaneously, the available research mainly focuses either on individual aspects of warehouse optimisation, or on general simulation modelling of logistics systems. This led to the need for a theoretical generalisation of FlexSim's capabilities specifically for 3D modelling of warehouse logistics, optimisation of storage processes, order processing, intra-warehouse transportation, and resource management.

The purpose of the study was to theoretically substantiate the possibilities of using FlexSim software for 3D modelling of warehouse logistics, optimising warehouse processes and supporting resource management in warehouse logistics systems. To achieve the goal, the following research objectives were defined: to characterise the theoretical foundations of 3D simulation modelling of warehouse logistics and FlexSim functionality for building virtual models of warehouse systems; to systematise the areas of using 3D modelling to optimise the storage of goods, order processing, intra-warehouse transportation, and inventory management; to substantiate the indicators and resource parameters that can be used to assess the impact of the simulation model on the productivity, balance, and manageability of the warehouse system.

Materials and Methods

The research was theoretical and analytical in nature and was conducted within the scientific field of computer science, modelling, and transport. The material basis of research was international standards, which provided a terminological, process, qualitative, risk-oriented, safe and environmental framework for analysing the use of three-dimensional simulation modelling in warehouse logistics. This approach allowed considering FlexSim software not only as a tool for building virtual models, but also as an element of system analysis of warehouse processes related to the storage of goods, order processing, intra-warehouse transportation, inventory management, and resource support for logistics operations.

The warehouse logistics system within the framework of the study was considered as a set of interrelated processes: acceptance of goods, identification of goods, placement in storage areas, replenishment of selection zones, picking orders, intra-warehouse transportation, packaging, shipment, and inventory control. This interpretation corresponds to a process approach in which the effectiveness of the system depends on the consistency of individual operations, resources, information rules, and service modes. In this context, the warehouse was considered not as a static storage space for products, but as a dynamic operating system in which spatial planning, material flows, personnel, technical means and digital modelling tools form a single mechanism for logistics productivity.

ISO/IEC 25002:2024 (2024) was used to substantiate the approach to evaluating FlexSim as a software modelling environment, since this standard defines the general logic of applying quality models in system and software engineering. Within the framework of the study, this allowed considering FlexSim through functional suitability for building a virtual warehouse model, the ability to reproduce warehouse processes, support for performance analysis, and suitability for scenario evaluation of management decisions. ISO 9001:2015 (2015) was applied to the process interpretation of warehouse logistics, where acceptance, storage, picking, transportation, packaging, shipment, and inventory control were considered as interrelated processes aimed at stable achievement of the planned result. ISO/IEC/IEEE 24765:2017 (2017) was used as a terminological basis for concepts related to systems, software, models, processes, and software engineering. The risk-based research framework was developed considering ISO 31000:2018 (2018), which allowed interpreting warehouse processes through potential operational risks: overloading of reception or shipment zones, queues, downtime of personnel and equipment, irrational routing, uneven use of warehouse space, lack of resources, and disruption of the rhythm of order processing. ISO 22301:2019 (2019) was used to consider the stability and continuity of warehouse processes under conditions of variable intensity of material flows, peak loads, or disruption of the normal operation of the warehouse. ISO 28000:2022 (2022) was used to consider the safe measurement of warehouse logistics as an element of the supply chain, where it was important to control the movement of goods, the reliability of intra-warehouse movement, reduce operational risks, and maintain flow manageability. ISO 14001:2026 (2026) has been used as a framework for examining the environmental aspects of optimising warehouse processes, specifically the reduction of unnecessary movements, minimisation of equipment downtime, optimisation of routes, more efficient use of resources, and the elimination of non-productive losses within the warehouse system.

FlexSim software (n.d.) was considered as an environment of three-dimensional simulation modelling, which allowed conceptually reproducing the spatial structure of the warehouse, the movement of goods, the work of personnel, the functioning of loading equipment, conveyor systems, automated vehicles, storage areas, picking, packaging, and shipment. In theoretical logic, FlexSim was interpreted as a tool for preliminary analysis of management decisions related to changes in warehouse planning, resource allocation, movement routing, order acquisition rules, inventory replenishment, and identifying bottlenecks in warehouse operations.

The theoretical model of the study covered four groups of warehouse processes. The first group concerned the storage of goods and provided for the analysis of product placement, use of warehouse space, availability of cells, replenishment of selection zones, and the impact of spatial organisation on the speed of operations. The second group covered order processing, including picking, sorting, packaging, preparing for shipment, and establishment queues in service areas. The third group was related to intra-warehouse transportation, movement routing, operation of loaders, trolleys, conveyors, Automated Guided Vehicles (AGV)/Autonomous Mobile Robots (AMR) solutions and interaction of traffic flows within the warehouse. The fourth group concerned resource management: personnel, equipment, warehouse zones, service time, inventory, and capacity of individual operational areas.

The research methodology was based on a combination of system analysis, structural and functional analysis, comparative analysis, conceptual modelling, process approach, risk-based analysis, and analytical systematisation. System analysis was used to consider warehouse logistics as an integral operating system, in which the spatial placement of zones, the rules for moving goods, the work of personnel, the use of technical means, order processing, and inventory control form an interdependent structure. This helped to determine that warehouse optimisation cannot be limited to changing one parameter, since reducing the route, increasing the number of employees, changing the storage location, or introducing additional equipment affect queues, throughput, resource congestion, and the rhythm of order fulfilment.

Structural and functional analysis was used to divide the warehouse system into key functional blocks: acceptance zone, storage zone, acquisition zone, packaging zone, shipment zone, transport routes, personnel, loading equipment, automated means of movement, information rules for order processing, and inventory control system. For each block, parameters were defined that can be represented in the 3D simulation model: flow rate, operation duration, waiting time, route length, resource loading level, throughput, frequency of queues, storage space usage level, and stability of operations in different load modes.

The process approach was used to consistently describe warehouse logistics as a chain of interrelated operations from the receipt of goods to their shipment. In this approach, each process was considered through input parameters, resource provision, operational action, output, and possible constraints. For example, the storage process was analysed through the availability of places, the rules of placement, and use of space; the order processing process – through the time of picking, queues, and loading of packaging zones; the transportation process – through routes, flow intersections and the use of equipment; the inventory management process – through replenishment of selection zones, control of balances and the rhythm of order fulfilment.

The conceptual modelling method was used to construct a generalised logic for applying FlexSim in a warehouse logistics system. The conceptual model provided for a sequence of analytical actions: defining the boundaries of the warehouse system, describing the main processes and resources, forming a virtual warehouse structure, establishing rules for the movement of goods and resources, selecting performance assessment indicators, comparing possible organisational scenarios and interpreting the results for making managerial decisions. In this logic, the 3D warehouse model was not an independent goal, but a tool for analysing the relationship between space planning, material flows, resources, and productivity.

Risk-based analysis was used to identify typical problems that can be identified or pre-evaluated using a simulation approach: congestion of individual zones, inconsistency of routes, occurrence of queues, downtime of personnel or equipment, insufficient capacity of operational areas, irrational placement of goods, delays in picking, and disruption of the rhythm of shipment. As part of this analysis, FlexSim was considered as a tool for preliminary identification of logistics constraints and selection of management decisions aimed at improving the stability of warehouse processes.

Analytical systematisation was used to select indicators that can be used to evaluate the operation of a warehouse system in a 3D FlexSim simulation model. The source basis for the selection was the official FlexSim documentation, which includes throughput, average resource usage, average waiting time, and maximum queue length as typical output indicators of the simulation model. The report also drew on industry materials from the Warehousing Education and Research Council (2025), which assessed the performance of warehouses and distribution centres using operational metrics such as cycle time, on-time dispatch, receiving and picking efficiency, warehouse capacity utilisation, order fulfilment accuracy, and order readiness for dispatch. On this basis, the following metrics were selected for the paper, as they align with both FlexSim's functional capabilities and the practice of warehouse performance benchmarking: order processing time, throughput, duration of intra-warehouse movements, utilisation of staff and equipment, queuing times, resource downtime, storage area utilisation, number of orders processed per unit of time, and system stability under varying material flow intensities.

The definition of ways to manage the resources of the warehouse system was carried out through grouping resources by functional purpose. The analysis included personnel, loading equipment, automated vehicles, storage areas, travel routes, inventory, maintenance time, operational area throughput, and output flow controllability. For each resource group, typical constraints, the method of representation in FlexSim, and the method of management influence were set. This approach linked resource management to the measured parameters of the model: the level of loading of personnel and equipment, downtime, route length, queues, throughput, stability of operations, and rhythm of shipment.

A separate methodological element was the development of a conceptual matrix of correspondence between warehouse processes, resources, FlexSim, capabilities and potential management decisions. In this matrix, the storage process correlated with the analysis of the use of space, availability of cells and placement of goods; the order processing process – with the time of completion, development of queues and loading of packaging zones; intra-warehouse transportation – with the length of routes, the use of equipment and flow intersections; inventory management – with the replenishment of selection zones, control of balances and the rhythm of order fulfilment; resource management – with the loading of employees, technical means, and operational zones. This approach allowed forming a complete scheme for theoretical evaluation of how FlexSim can support warehouse logistics optimisation.

The methodological logic of the study was aimed at developing a scientifically based concept of using FlexSim for analysing and improving warehouse logistics processes. It helped to determine which warehouse operations can be represented as a three-dimensional simulation model, which resources are subject to analytical control, which indicators are appropriate to use for performance assessment, and which management decisions can be supported by means of simulation modelling. As a result, the methodology combined a standardised terminology and process framework, a structural description of the warehouse system, and a conceptual representation of FlexSim as a tool for optimising storage, transportation, processing of goods, and resource management.

Results

Structuring of a warehouse logistics system: FlexSim process modelling. The results of structuring the warehouse logistics system showed that it is advisable to consider the warehouse not as an isolated space for storing goods, but as a process system in which material flows, personnel, technical means, processing zones, movement rules, and information operations interact sequentially and simultaneously. In such a system, acceptance of goods, identification of goods, placement in storage areas, replenishment of selection zones, acquisition, intra-warehouse transportation, packaging, shipment, and inventory control form a single operational chain. Violation of the consistency of at least one component affects other elements of the system: a delay in the reception area increases the load on transport routes, irrational placement of goods prolongs recruitment, and uneven loading of equipment causes queues and downtime. This is why 3D simulation modelling in FlexSim (n.d.) allows representing the composition as an interconnected spatial and process model, in which each element has not only a physical location, but also a functional role in ensuring productivity. To summarise the structural components of a warehouse logistics system that can be represented in FlexSim, Table 1 is formed.

Table 1. Structural components of a warehouse logistics system as a 3D modelling object in FlexSim

Structural component of the warehouse system	Functional purpose in the logistics process	Representation in a 3D FlexSim model	Potential impact on warehouse performance
Product acceptance zone	Ensures the receipt of cargo, initial verification, identification, and transfer of goods to further operations	Dock gates, flow entry points, receiving workstations, waiting queues	Determines the initial rhythm of the material flow and can form the first bottlenecks of the system
Cargo identification and control zone	Provides verification of conformity of goods, labelling, scanning and information inclusion of cargo in the warehouse system	Verification stations, scanners, logical routing points, rules for switching to storage areas	Affects the speed of product entry into the system and the accuracy of subsequent inventory management
Storage areas and shelving systems	Perform the function of placing, accumulating, and storing product units until the moment of selection	Racks, storage cells, accumulation blocks, spatial warehouse objects	Determine the level of space usage, availability of goods, and length of routes during recruitment
Selection replenishment zone	Facilitates the transfer of goods from reserve storage to active picking areas	Intermediate buffers, top-up routes, and product transfer points	Supports continuous picking and reduces the risk of order processing being stopped due to a shortage of products in the selection area
Order acquisition zone	Provides selection of products according to the order structure	Selection workstations, employee routes, trolleys, picking process rules	Directly affects the order processing time, staff workload, and accuracy of operations
Intra-warehouse transport routes	Ensure the movement of goods between the zones of acceptance, storage, picking, packaging, and shipment	Transport trajectories, route nodes, flow intersections, traffic restrictions	Determine the duration of movements, the risk of flow intersections, queues, and equipment downtime
Loading equipment and manual vehicles	Provide physical movement of pallets, containers, boxes or components	Forklift, transporter, pallet truck, operator-based transport objects	Affect the capacity of transport operations, the level of downtime, and the balance of resources
Conveyor systems	Provide continuous or semi-automatic movement of goods between operating areas	Conveyor objects, accumulation conveyors, transfer points	Increase the rhythm of the flow, but can form bottlenecks when individual sections are overloaded
Automated controlled vehicles and autonomous mobile robots	Provide automated intra-warehouse movement without constant manual control	Automated Guided Vehicles, AGV, Autonomous Mobile Robots, AMR, network paths	They allow analysing automated routing, loading of transport units, and stability of movement
Packing and consolidation area	Provides integration of goods into orders, packaging, labelling, and preparation for shipment	Packaging workstations, order buffers, pre-shipment queues	Affects the final order processing time and can be a critical node at high flow rate
Shipment area	Ensures the transfer of finished orders to the transport supply system	Dock gates, flow points, shipment queues, vehicles	Determines the final capacity of the warehouse and the rhythm of order fulfilment

Table 1. Continued

Structural component of the warehouse system	Functional purpose in the logistics process	Representation in a 3D FlexSim model	Potential impact on warehouse performance
Staff and working rules	Provide acceptance, control, selection, packaging, and movement operations	Operators, task executers, dispatching rules, work schedules	Determine the workload of labour resources, waiting time for operations, and the level of operational stability
Queues, buffers, and routing rules	Regulate the sequence of processing goods, accumulation of cargo and the choice of areas of movement	Queue objects, buffers, routing logic, process flow rules	Allow identifying bottlenecks, estimating delays, and supporting scenario analysis of the warehouse system

Source: compiled by the author based on the process approach to warehouse logistics in accordance with ISO 9001:2015 (2015), the terminology provisions of ISO/IEC/IEEE 24765:2017 (2017), and the functional analysis of FlexSim software suite (n.d.)

Table 1 analysis showed that the 3D model of a warehouse logistics system in FlexSim should cover not only the physical objects of the warehouse, but also the logic of their interaction. The most important components for modelling are those in which spatial placement directly affects the time of operations: reception, storage, picking, packaging, shipment, and intra-warehouse routes. Simultaneously, intangible elements of the model are equally important – routing rules, service sequence, queues, buffers, staff work schedules, and the logic of using equipment. They determine whether the warehouse system will work rhythmically, or whether individual sections will start accumulating delays.

Therefore, structuring a warehouse as a modelling object has shown that FlexSim can be used to analyse the interdependence between the spatial configuration of a warehouse, material flows, resources, and rules for performing operations. It was revealed that the central element of the 3D model is not a separate warehouse area, but the trajectory of goods passing through the entire system: from receipt to shipment. If the storage area is located without considering the frequency of product selection, picking routes are lengthened, the load on personnel and equipment increases, and the packaging area receives an uneven flow of orders. If the reception area is not consistent with the identification and placement capacity, queues arise at the beginning of the process, which further affect the use of shelving zones and transport resources. If the shipment area has a lower throughput than previous operations, finished orders are accumulated in buffers, which reduces the efficiency of the entire warehouse. Therefore, the representation of a warehouse in FlexSim should consider not only the geometry of the space, but also the rhythm of passing commodity units through the sequence of operations.

Generalisation of the warehouse logistics system structuring has shown that three-dimensional simulation modelling in FlexSim allows forming a holistic view of the warehouse as a controlled process system. The model should include physical components: zones, racks, routes, vehicles, workstations; and logical components: product traffic rules, queues, buffers, service priorities, and resource usage modes. The established pattern is that warehouse productivity is formed not by a separate operation, but by consistency between the spatial structure, material flows, personnel, equipment, and information rules. This means that FlexSim can be used as a tool for preliminary detection of structural limitations of the warehouse system, in particular, congested areas, irrational routes, insufficient capacity of individual sections, and uneven use of resources.

Systematisation of areas of three-dimensional modelling of warehouse processes. The results of systematisation of areas of using three-dimensional modelling showed that optimisation of warehouse logistics in FlexSim covers not only the acceleration of individual operations, but also the coordination of spatial placement of goods, order processing rules, logic of replenishment of selection zones, and inventory control. In the warehouse system, the processes of storage, picking, sorting, packaging, and managing balances do not function in isolation: irrational placement of goods increases the length of routes, uneven replenishment of selection zones disrupts the rhythm of picking, and insufficient control of balances creates the risk of delays in order fulfilment. In this context, the 3D model allows representing the composition as an interconnected system of spatial, process, and resource solutions. It was determined that the key advantage of three-dimensional modelling is the ability to simultaneously analyse the physical placement of goods, the movement of material flows, the loading of zones, and the potential risks of queues or unproductive movements. To summarise the areas of using 3D modelling in optimising storage, order processing, and inventory management, Table 2 was formed.

Table 2. Areas of using 3D modelling to optimise product storage, order processing, and inventory management

Area of warehouse process optimisation	Logistics content of the process	Representation in a 3D FlexSim model	Rating indicator and numerical benchmark
Optimisation of product placement in storage areas	Determining the location of goods based on the frequency of selection, dimensions, weight, and handling mode	Shelving cells, storage areas, placement rules, logic of access to goods	Average storage capacity usage – ≥90%; peak storage capacity usage – ≥100%

Table 2. Continued

Area of warehouse process optimisation	Logistics content of the process	Representation in a 3D FlexSim model	Rating indicator and numerical benchmark
Improving the availability of storage cells	Providing access to the necessary product items without overloading individual sections	Cells with different availability levels, approach routes, and selection points	Internal order processing cycle – <3.36 hours; order completion accuracy – ≥99.68%
Rationalising the use of warehouse space	Matching the capacity of storage areas, passageways, buffers, and operating areas	Spatial configuration of the warehouse, racks, passageways, buffer zones, traffic restrictions	Average storage capacity usage – ≥90%; peak storage capacity usage – ≥100%
Replenishment of selection zones	Moving items from backup storage to active pick-up zones	Top-up buffers, travel routes, top-up rules, product transfer points	Time from acceptance of the product to its placement in the warehouse – <3.5 hours; accuracy of inventory accounting at the place of storage – ≥99.5%
Optimisation of order acquisition	Selection of products according to the order structure and picking rules	Picker routes, selection workstations, trolleys, queues, selection sequence rules	Order completion accuracy – ≥99.68%; selection and shipment productivity – ≥70 order lines/ man-hour
Sorting products and orders	Distribution of product units or orders by destination, customer, batch, or shipment route	Sorting points, pipelines, buffers, flow distribution rules	Timely readiness of orders for shipment – ≥99.5%; full order processing cycle – <6 hours
Packaging and order consolidation	Combining selected goods, packaging, labelling, and preparation for transfer to the shipment zone	Packaging workstations, ready order buffers, pre-shipment queues	Timely readiness of orders for shipment – ≥99.5%; internal order processing cycle – <3.36 hours
Balance control and inventory management	Maintaining consistency between actual balances, staffing requirements, and replenishment plan	Logical rules for inventory control, replenishment levels, and the relationship between storage and selection zones	Accuracy of inventory accounting at the place of storage – ≥99.5%; share of supplier orders received without damage – ≥99.07%
Detecting congested areas	Identifying areas where goods accumulate, queues, or waiting for resources	Queues, buffers, thread intersection nodes, loaded workstations	Average waiting time; maximum queue length; full order processing cycle – <6 hours
Reducing unproductive movements	Detection of unnecessary routes, repeated movements, flow intersections, and irrational movement of vehicles	Transport trajectories, personnel routes, movement of loaders, automated vehicles	Share of overtime hours in total working hours – <1.88%; selection and shipment productivity – ≥70 order lines/man-hour

Source: compiled by the author based on Warehousing Education and Research Council (2025) on reference performance indicators for warehouse and distribution centres and official FlexSim documentation (n.d.) on performance indicators, and initial statistical parameters of the simulation model

Analysis of Table 2 shows that the spatial, process, and resource levels of 3D modelling should be evaluated using quantitative operational metrics. For the placement of goods and the use of space, the reference points are the average level of storage capacity utilisation ⩾90% and peak capacity utilisation ⩾100%. Selection accuracy ⩾99.68% and productivity ⩾70 order lines/man-hour are key for completing orders. For replenishment, packaging and shipment, the time from acceptance of the product to its placement in the warehouse <3.5 hours, the internal order processing cycle <3.36 hours, the full order processing cycle <6 hours and the timely readiness of orders for shipment ⩾99.5% are important. In FlexSim, these parameters can be represented in terms of throughput, average resource usage, average waiting time, maximum queue length, order completion time, executor workload, and output stream statistics. This allows using the 3D model not only to visualise the composition, but also to check whether the simulated configuration meets the target operational criteria. Generalisation of the areas of using 3D modelling showed that the greatest optimisation effect is formed when the processes of storage, order processing, and inventory management are analysed not separately, but as interrelated elements of one warehouse cycle. Rational placement of goods increases the availability of cells and reduces acquisition routes; synchronous replenishment of selection zones maintains the continuity of order processing; control of balances ensures the stability of operations; and coordination of packaging and shipment prevents the accumulation of finished orders in buffer zones. The established pattern is that the 3D FlexSim model allows moving from local improvement of a separate warehouse operation to system optimisation of the logistics process, within which productivity depends on the spatial organisation, rules of movement of goods, availability of inventory and balance of resources.

Analysis of FlexSim's capabilities for building a virtual warehouse model. The results of the analysis of FlexSim capabilities showed that it is advisable to consider this software environment as a tool for building a complete virtual warehouse model, which combines the spatial representation of the object, the process logic of product movement, resource support for operations, and a system of performance indicators. Unlike a static warehouse plan, the virtual model in FlexSim reflects not only the location of zones, racks, routes, and technical means, but also the sequence of processing goods, forming queues, loading employees, using transport resources, and the relationship between individual operational areas. This helped to evaluate the performance of the warehouse system through the dynamics of its operation, and not just through the nominal capacity or quantity of equipment. Within this logic, the effectiveness of FlexSim is determined by the ability to reproduce a warehouse as a programmatically described system with material flows, resources, events, routing rules, and planning change scenarios. Table 3 was created to summarise the key FlexSim features associated with creating a virtual warehouse model and evaluating performance.

Table 3. FlexSim features for creating a virtual warehouse model and evaluating performance

FlexSim function block	Practical use in the virtual warehouse model	Performance parameters to be evaluated	Managerial importance for warehouse logistics
3D layout and object structure of the model	Construction of a spatial configuration of a warehouse with reception, storage, picking, packaging, shipment areas, aisles, racks, docks, and workstations	Route length, zone availability, area usage level, and spatial restrictions	Allows assessing whether warehouse planning corresponds to the logic of product movement and whether the space configuration itself creates prerequisites for delays
Library Objects	Use of typical model objects: Source, Queue, Processor, Rack, Conveyor, Sink, Operator, Transporter, Elevator, Task Executer	Operation throughput, waiting time, number of processed units, object load	Allows recreating the warehouse as a system of interrelated processes and comparing the performance of individual operational areas
Process Flow	Formalisation of the logic of warehouse operations: acceptance, verification, placement, replenishment, selection, packaging, sorting, shipment	Sequence of operations, cycle time, delays between stages, stability of order passage	Provides analysis not only of the physical movement of goods, but also of service rules, priorities, transition conditions between operations, and management scenarios
A* Navigator and transfer networks	Construction of routes for personnel, loaders, trolleys, AGV/AMR and transport units between warehouse zones	Travel duration, route length, frequency of traffic intersections, downtime while driving	Allows identifying irrational routes, flow conflicts, congested passageways, and areas with an increased risk of delays
Rack and Storage Logic	Modelling of shelving, product placement, cell availability, backup storage, and active selection zones	Cell occupancy, product availability, placement time, selection time, deposit frequency	Allows evaluating how storage rules affect the speed of acquisition, area utilisation, and stability of inventory management
Conveyor Module	Reproduction of conveyor lines, sorting areas, storage areas and movement of goods between operating stations	Flow rate, accumulation on sections, conveyor travel time, line loading	Allows assessing the rhythm of movement of goods and identifying areas where a continuous flow turns into a source of queues
Task Executers: Operators, Forklifts, Transporters	Modelling the work of employees, loaders, vehicles, and task performers in warehouse operations	Load level, downtime, task completion time, number of completed operations	Supports resource balancing, identifying a shortage or surplus of employees and equipment, and evaluating the effectiveness of task allocation
Dashboards, Statistics Collector, and Output Analysis	Collecting and summarising model performance indicators in the form of graphs, tables, statistical panels, and output reports	Cycle time, throughput, utilisation, waiting time, idle time, WIP, bottleneck indicators	Provides a transition from visual observation to analytical performance evaluation and comparison of alternative scenarios
Experimenter and Scenario Analysis	Comparison of planning options, number of resources, routing, replenishment modes, and order flow intensity	Changes in throughput, processing time, resource workload, queues, and downtime between scenarios	Enables a preliminary assessment of the consequences of management decisions before they are implemented in an actual warehouse system
Bottleneck Analysis	Identification of areas where queues accumulate, downtime occurs, or the passage of material flow is restricted	Blocking frequency, waiting time, critical resource load level, throughput constraints	Allows setting which zone, resource, or service rule limits warehouse performance

Source: compiled by the author based on FlexSim (n.d.)

Table 3 analysis shows that the practical value of FlexSim for warehouse logistics lies in the combination of object, process, resource, and statistical modelling levels. At the object level, the programme allows building the spatial structure of a warehouse using zones, racks, conveyors, docks, transport routes, and typical warehouse facilities. However, warehouse productivity is determined not only by how elements are placed, but also by how product units move between them, how tasks for personnel and equipment are formed, how queues accumulate, and how resource utilisation changes over time. This is why Process Flow, Task executors, A* Navigator, Statistics

Collector, and Experimenter are particularly important, as they move a 3D model from the visual schema level to the managed simulation system level. It was found that the relationships between them, rather than isolated 3D objects, are most applicable for evaluating warehouse performance. For example, the Rack object has Management Value only when it is associated with product placement rules, selection routes, replenishment of recruitment zones, and loading of task performers. The Conveyor Module provides a full analytical effect only when estimating the accumulation in certain areas, the speed of passing goods, and synchronisation with packaging or sorting. For loaders, operators, automated controlled vehicles / autonomous mobile robots and vehicles, the key is not the very fact of their presence in the model, but the measured parameters of operation: load level, downtime, route length, number of completed tasks, and the presence of traffic conflicts, which corresponds to the logic of FlexSim output indicators for resource use, waiting, queues and distance travelled by transport resources. Therefore, FlexSim allows evaluating the performance of a warehouse as a result of the interaction of space, process, and resources. Dashboards, Statistics Collector, Output Analysis, and Experimenter play a separate analytical role. They allow moving from visual observation of the movement of objects in a 3D scene to a systematic comparison of indicators. For warehouse logistics, this is of methodological importance, since the effectiveness of the simulated warehouse configuration should be confirmed not only by a visual representation of the processes, but also by quantitative indicators: order processing cycle time, throughput, average waiting time, resource loading level, downtime, queue length, and stability of orders passing through consecutive operations (Warehousing Education and Research Council, 2025). In this sense, FlexSim provides not only the creation of a virtual warehouse model, but also analytical verification of how changes in planning, routes, or resource provision can affect performance. Generalisation of FlexSim's capabilities has shown that its effectiveness in warehouse logistics is determined by the ability to combine a three-dimensional spatial model with formalised process logic and a system of initial indicators. The most important thing is not the 3D visualisation itself, but the ability to link each warehouse element to a specific operation, resource, route, and performance indicator. This allows identifying bottlenecks, evaluating the load of personnel and equipment, comparing planning scenarios, determining the consequences of changing storage or acquisition rules, and precheck management decisions without interfering with the actual warehouse infrastructure. It is this integration of space, process, resources, and statistics that makes FlexSim a suitable tool for theoretical substantiation of warehouse logistics system optimisation.

Justification of simulation methods of warehouse resource management. The results of systematisation of resource management methods have shown that in a warehouse logistics system, the resource effect is formed not only by the number of employees, equipment or warehouse zones, but also by the degree of their coordinated use within a single material flow. An excess of a single resource does not always increase productivity if the restriction occurs in another part of the system: additional loaders do not eliminate delays due to insufficient throughput of passageways, an increase in personnel does not speed up shipment due to overloaded docks, and an expansion of the storage area does not improve acquisition if goods are placed without considering the frequency of selection. Therefore, it is advisable to consider resource management in the context of 3D simulation modelling as a process of balancing personnel, technical means, routes, inventory, warehouse zones, service time, and operational throughput. The simulation approach in FlexSim enables the early identification of resource imbalances, bottlenecks, downtime, queues, flow conflicts, and risks of disruptions to the shipment schedule. Table 4 was developed to generalise methods for managing warehouse system resources based on 3D simulation modelling.

Table 4. Methods for managing warehouse system resources based on 3D simulation modelling

Warehouse system resource group	Typical resource constraints	Representation in FlexSim	Resource management method
Reception, picking, packaging, and control personnel	Uneven workload, waiting for tasks, shortage of employees in peak zones	Operators, task executors, change schedules, task assignment rules	Reallocation of personnel between zones, changing task priorities, balancing changes
Loading equipment, manual vehicles, AGV/AMR	Waiting for vehicles, idling, crossing routes, blocking passageways, uneven use of transport units	Forklifts, Transporters, Pallet Trucks, Automated Guided Vehicles, Autonomous Mobile Robots, Network Paths	Optimise the number of vehicles, route network, call rules, waiting areas, and movement priorities
Warehouse areas of acceptance, storage, picking, packaging, and shipment	Overloading of sections, accumulation of cargo, insufficient capacity of zones	Processors, Queues, Buffers, Storage Areas, Dock Objects	Balancing the bandwidth of zones, changing the size of buffers, switching rules between operations, and the number of service channels
Intra-warehouse travel routes	Elongated trajectories, flow intersections, congested passageways, irrational movement of personnel and equipment	A* Navigator, Network Nodes, Travel Paths, Route Restrictions	Rationalisation of the route network, breeding of oncoming flows, changing entry, and exit points between zones

Table 4. Continued

Warehouse system resource group	Typical resource constraints	Representation in FlexSim	Resource management method
Stocks and selection zones	Shortage of goods in the picking area, excessive accumulation in backup storage, untimely replenishment	Rack Logic, Storage Rules, Replenishment Triggers, Inventory Levels	Coordination of replenishment rules, minimum inventory levels, frequency of selection and placement of goods
Throughput and controllability of the output stream	Mismatch of productivity between acceptance, picking, packaging and shipment; violation of the rhythm of shipment	Throughput Statistics, Queues, Bottleneck Indicators, Output Analysis, Scenario Analysis, Performance Dashboards	Levelling the performance of consecutive sections, changing priority rules, evaluating critical scenarios

Source: compiled by the author based on the risk-based framework ISO 31000:2018 (2018), provisions on sustainability and process continuity ISO 22301:2019 (2019), the security approach to supply chains ISO 28000:2022 (2022), the Environmental Resource rationalisation framework ISO 14001:2026 (2026), the analytical review of FlexSim capabilities (n.d.), and operational indicators of warehouse and distribution centres Warehousing Education and Research Council (2025)

Table 4 analysis shows that it is advisable to evaluate warehouse system resource management in FlexSim through quantitative indicators of loading, cycle time, throughput, queues, and timely shipment. Personnel, equipment, automated vehicles, storage areas, routes, inventory, and service times affect related operations, so they cannot be considered in isolation. For the workforce, the key benchmarks are the productivity of selection and shipment ⩾70 lines of orders/man-hour and the share of overtime <1.88%. If these indicators are not achieved, the model records not only a shortage of personnel, but also possible inconsistencies between the recruitment, packaging, and shipment zones. For technical and automated transport resources, the time from product acceptance to placement <3.5 hours, the average waiting time, the maximum queue length, and the level of resource usage are important. Increasing the number of loaders, transporters, automated controlled vehicles, or autonomous mobile robots does not automatically improve productivity if the route network, waiting points, call rules, and travel priorities remain inconsistent. In this case, queues, aisle blockages, and traffic conflicts may increase in the model. For warehouse zones and routes, the estimate is associated with average storage capacity usage ⩾90%, peak capacity usage ⩾100%, internal order processing cycle <3.36 h, and full order processing cycle <6 h. Exceeding time benchmarks or accumulating queues in buffers before packaging and shipment indicates a resource imbalance between consecutive warehouse sections. For stocks and selection zones, the accuracy of inventory accounting at the storage location ⩾99.5% and the accuracy of completing orders ⩾99.68% are crucial, since late replenishment or incorrect placement of goods directly affects the rhythm of order fulfilment. Therefore, the simulation approach helps to identify not only a lack of personnel, equipment, or space, but also an incorrect configuration of their use. In FlexSim, resource constraints are manifested due to exceeding the cycle time, increasing the average waiting time, increasing the maximum queue length, resource downtime, and disrupting the timeliness of shipment, for which the target is ⩾99.5%. Therefore, resource management in a 3D model is not aimed at maximising an individual resource, but at maintaining a consistent pace of product passage through acceptance, storage, picking, packaging, and shipment.

Generalisation of resource management methods has shown that 3D modelling in FlexSim forms the basis for the transition from quantitative resource accumulation to system balancing. The efficiency of warehouse logistics is determined not by the maximum number of personnel, equipment, or area, but by the correspondence of resources to the intensity of material flow, the spatial configuration of the warehouse, service rules, and the capacity of consecutive sections. The established pattern is that resource management through a simulation approach allows identifying hidden limitations that are not manifested in static planning: downtime, queues, flow intersections, a shortage of performers at peak points, excessive equipment in an inefficient route network, and a violation of the rhythm of shipment. This justifies the use of FlexSim as a tool for preliminary resource balancing of the warehouse system, aimed at improving the productivity, sustainability, and manageability of logistics processes.

FlexSim integrated model-optimisation of warehouse resource processes. Generalisation of the results of structuring the warehouse logistics system, systematisation of 3D modelling areas, analysis of FlexSim capabilities and resource management methods showed that warehouse optimisation is formed as a consistent relationship between the process, its digital representation, resource provision, productivity indicators, and management decisions. It was established that the three-dimensional model in FlexSim has the greatest analytical value when it reflects not only the spatial planning of the warehouse, but also the logic of the movement of goods, the work of personnel and equipment, queues, buffers, routing rules, and the relationship between individual operational zones. In this model, the warehouse process is the initial element: acceptance, storage, acquisition, intra-warehouse transportation, packaging, shipment, and inventory control set the structure of the digital representation. The 3D model element in FlexSim concretises this process through zones, racks, routes, processing points, queues, personnel, machinery, automated vehicles, and autonomous mobile robots. The resource block relates the model to the actual limitations of the warehouse system: personnel, loading equipment, automated transport, storage space, maintenance time, and inventory. Performance indicators reflect the result of the interaction of these elements and allow moving from visual representation to management analysis. To generalise the revealed logic, an integral conceptual model was created, presented in Figure 1.

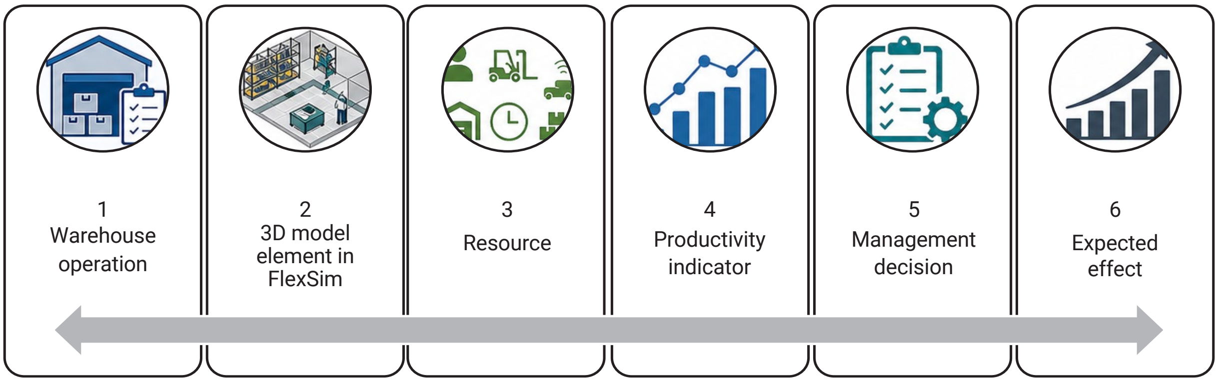

Figure 1. Generalised model of the relationship between 3D modelling, resource management, and warehouse system performance

Source: compiled by the author based on integration of the results of structuring the warehouse logistics system, systematisation of 3D modelling areas, analysis of FlexSim capabilities (n.d.), and resource management methods considering ISO/IEC 25002:2024 (2024), ISO 9001:2015 (2015), ISO/IEC/IEEE 24765:2017 (2017), ISO 31000:2018 (2018), ISO 22301:2019 (2019), ISO 28000:2022 (2022), ISO 14001:2026 (2026)

The integral model in Figure 1 was constructed as a sequence of transitions from the warehouse process to the expected operational effect. The first block captures the process basis of the model: the warehouse is not considered as a static object, but is fed through the operations of receiving, storing, picking, transporting, packaging, shipping, and inventory control. The second block translates these processes into a 3D FlexSim environment, where they get a spatial and logical representation across storage areas, racks, routes, processing points, queues, personnel, equipment, and automated transport solutions. The third block shows that the efficiency of a warehouse system depends on resource support, in particular, on the consistency of personnel, loading equipment, automated transport, warehouse space, service time, and inventory. The fourth block of the model reflects the transition from resource description to performance evaluation. It is the indicators of cycle time, throughput, resource utilisation, waiting time, downtime share, space usage, and flow stability that determine which elements of a warehouse system limit its effectiveness. If the waiting time in the model increases, this indicates the presence of queues or insufficient capacity of a particular section; if the share of downtime increases, this indicates inconsistencies between tasks, resources, and routes; if the flow stability decreases, this means that the warehouse system loses its rhythm due to overload, resource scarcity, or irrational spatial planning. Thus, performance indicators in the model serve as an analytical indicator that connects the 3D representation of the composition with the subsequent management decision. The fifth block of Figure 1 shows the management interpretation of 3D modelling results. These solutions include redevelopment of zones, changing routes, balancing personnel, reallocating equipment, setting up inventory, and eliminating bottlenecks. It is important that these decisions do not arise as isolated actions, but are formed based on the relationship between a specific warehouse process, model element, resource, and performance indicator. For example, changing the route makes sense only when excessive travel length, flow intersections, or simple equipment is detected; reallocation of personnel is appropriate in case of uneven loading of operational areas; inventory adjustment is necessary when a shortage in the selection area disrupts the rhythm of completing orders. The final block of the model captures the expected effect: reduced downtime, reduced queues, increased order processing speed, more efficient use of resources, increased productivity, increased stability and manageability of the warehouse system.

Generalisation of the integral conceptual model showed that the use of FlexSim for warehouse logistics optimisation is systemic in nature and can be represented as a consistent analytical transition "warehouse process – element of the 3D model – resource – performance indicator – management decision – expected effect". In this logic, FlexSim is considered not only as a means of building a three-dimensional virtual model of a warehouse, but also as a tool for analytical combination of warehouse processes, resources, routes, processing zones, product movement rules, and productivity indicators. The established pattern is that optimisation of storage, order processing, intra-warehouse transportation, and inventory management is achieved not through isolated improvement of a separate operation, change of planning or increase in the number of equipment, but through coordination of the entire system of spatial, process, and resource parameters. The results showed that FlexSim can be used to pre-identify structural constraints, bottlenecks, queues, downtime, irrational routes, flow intersections, resource imbalances, and risks of disrupting the rhythm of warehouse operations.

Discussion

The theoretical results obtained confirmed that the optimisation of warehouse logistics in the FlexSim environment should not be considered as a local improvement of an individual operation, but as a coordination of the spatial structure of the warehouse, material flows, resources, and service rules. Especially important is the established relationship between the placement of goods, the routing of movements and resource rationality, since these factors determine the occurrence of queues, downtime and excessive movements in the warehouse system. This logic is consistent with research by M. Füchtenhans *et al.* (2021), who showed that even auxiliary infrastructure solutions in a warehouse environment can affect energy costs and warehouse efficiency if they are related to space and resource usage modes. Within the framework of the generated results, a similar conclusion was expressed in the fact that a 3D warehouse model should reflect not only storage areas and routes, but also the logic of using space, equipment, and service time. The energy and resource aspect of this problem was developed based on the study by H.-W. Jeon *et al.* (2023), where a simulation design is applied to analyse energy consumption and order delays in warehouse systems. The theoretical model correlated with the current approach, since it relates warehouse performance not only to processing speed, but also to downtime, queues, uneven load, and resource losses.

Further comparison of the results showed that technical resource management is one of the key areas of practical use of three-dimensional modelling. The study by A. Ebrahimi *et al.* (2023) focused on picker-to-part warehouses with electric loaders, where a comparison of optimisation algorithms showed a link between energy consumption, order delays, and technique usage logic. This is directly consistent with the conclusion that increasing the number of loaders or automated vehicles does not guarantee increased productivity without correcting routes, waiting points, and dispatching rules. The question of the transition from a separate simulation model to a digital twin was revealed in the study by A. Ferrari *et al.* (2023), which proposed an approach to the development and validation of models of automated storage and selection systems. In the context of this study, this confirmed the feasibility of treating FlexSim as a tool that can combine spatial representation of composition, process logic, and performance indicators in a single digital structure. An important confirmation of the obtained theoretical results is the study by V. Singbal & G.K. Adil (2023), which developed a data-driven simulator for unit-load multi-aisle automated storage and retrieval systems. Its results showed the value of a parameterised description of the warehouse system, which is consistent with our structuring of the warehouse model through zones, racks, routes, queues, task performers, and product movement rules. A similar logic was reflected in the paper by Y. Zeng *et al.* (2024), where the dynamic simulation framework for parallel warehouse planning systems is based on the hybrid modelling paradigm. This resonates with the conclusion that warehouse productivity is determined not by a separate process, but by the interaction of several parallel operational circuits: storage, replenishment, picking, packaging, transportation, and shipment. In this sense, FlexSim is valuable precisely as an environment that can combine the physical and logical components of a warehouse system.

The resulting integral model also correlates with current approaches to digital twins of smart composition. In the study by Z.U. Rizqi *et al.* (2024), simulation-based digital twin was seen as a smart warehouse standardisation area, highlighting the need for a consistent representation of processes, resources, data, and management rules. In this model, a similar idea was implemented through the sequence "warehouse process – element of a three – dimensional model – resource – productivity indicator – management decision – expected effect". The study by H. Di (2024), dedicated to the automated warehouse simulation platform based on virtual visualisation, also confirmed the importance of combining spatial visibility and process logic. However, the results of this study showed that visualisation has analytical value only when it is related to routes, queues, resource load, throughput, and scenario changes in planning. The established structure of the results was also consistent with multi-method approaches to modelling warehouse processes. The paper by P. De Vito *et al.* (2024) showed that warehouse processes can be analysed using a combination of different simulation methods, since a separate approach does not always reflect the complete behaviour of the system. The theoretical results of this study supported the following position: warehouse productivity is formed at the intersection of spatial, process, resource, and risk-oriented parameters. In the systematic review by E. Aretoulaki *et al.* (2024), discrete-event modelling and digital doubles in warehouse logistics were defined as complementary areas that ensure the transition from process description to digital analysis of warehouse behaviour. This fully correlates with the presented conclusion that FlexSim cannot be reduced to a three-dimensional visualisation tool: its main value lies in linking the warehouse model to performance indicators and management decisions. The scientific context of the results obtained was reinforced by the conclusions of E. Bottani & G. Casella (2024), who considered discrete event modelling in logistics and supply chain management as one of the key tools for analysing complex operating systems. As part of this study, this was reflected in the fact that queues, downtime, waiting times, resource congestion, and zone throughput were considered as central indicators of warehouse productivity. The study by C. Kogler & P. Maxera (2025), dedicated to combining simulation and machine learning in supply chain management, showed a trend towards integrating modelling with intelligent analytical approaches. Although the research was theoretical and analytical in nature and did not provide for its own integration of machine learning, the developed model provided the basis for such development, since it clearly defined the processes, resources, and indicators that can be used for further scenario or forecast analysis.

A separate area of discussion concerns order acquisition, which was identified in the results obtained as one of the most sensitive processes for spatial planning and resource support. The paper by P. Rymarczyk *et al.* (2024) considered order picking optimisation through routing and clustering, which confirmed the importance of rational product placement, cell availability, and reduced unproductive movement. In this systematisation, these aspects were reflected through the relationship between storage areas, picker routes, picking process rules, and order processing time. The study by W. Lewicki *et al.* (2024), which developed a simulation model using FlexSim to improve the functioning of production processes, demonstrated the wider applicability of this tool for analysing operating systems. For warehouse logistics, this means that FlexSim can be used not only to reproduce the movement of goods, but also to compare options for planning, resource provision, and organising work processes. The results on the management of automated transport resources are consistent with the study by C. Yu *et al.* (2023), where dynamic planning optimisation for multi-AGV intelligent warehouse was considered based on bidirectional channels. Within the generated model, this problem was reflected through intra-warehouse movement routes, flow intersections, passageway blocks, waiting points, and dispatching rules. This confirmed the conclusion that automation is not a self-sufficient factor in improving productivity: its effect depends on the consistency of the route network, the number of transport units, and the rules for connecting them to the operational process. The study by S. Pawlak *et al.* (2025) used discrete event simulation to analyse electricity consumption in logistics processes, which enhanced the resource and environmental measurement of the results obtained. This aspect was revealed due to the reduction of unnecessary movements, idle mileage of equipment, downtime, and unproductive use of space.

The issue of practical improvement of warehouse operations through simulation was revealed in the paper by M. de Carvalho Paula *et al.* (2025), where modelling was used to effectively design planning and improve picking by line operation. This is directly consistent with the conclusion that the greatest optimisation effect is formed not as a result of an isolated change in a single operation, but through a combination of product placement, selection routes, replenishment of acquisition zones, and packaging capacity. The environmental and energy measurement of warehouse optimisation was further confirmed by L. Cannava *et al.* (2025), where a simulation approach was used to improve the energy efficiency and environmental performance of warehouses. In the above model, this area was reflected through resource-saving logic: reducing unnecessary routes, using equipment more efficiently, reducing downtime, and reducing unproductive time and energy costs. The study by A. Žagar *et al.* (2025) developed a simulation model of automated storage and retrieval systems for long and heavy loads, which emphasised the importance of adapting the model to the type of cargo, work area, technical resource, and movement restrictions. In the results of this paper, this logic was reflected due to the need to link each warehouse process with a specific element of the three-dimensional model, resource, and performance indicator. Further confirmation was provided by A.C. Silva *et al.* (2026), in which simulation-based approach was used to improve picking-by-line operations. This resonates with the conclusion that the acquisition, packaging, and shipment processes should be analysed as interrelated links, since local acceleration of selection can create new queues in subsequent operational areas.

Thus, the comparison of the obtained theoretical results with contemporary research confirmed that FlexSim should be considered as a tool for system analysis of warehouse logistics, in which a three-dimensional representation is combined with process logic, resource balancing and performance evaluation. Research on energy efficiency, digital doubles, automated storage systems, order picking, multi-AGV planning, and discrete-event simulation is consistent with the main conclusion of this paper: warehouse performance is determined not by a single parameter, but by the interaction of space, material flow, resources, routes, and service rules. An integral model has been developed to clarify this approach, since it translates the optimisation of the warehouse system into the sequence "warehouse process – element of a 3D model – resource – productivity indicator – management decision – expected effect". The combination of the discussed results showed that 3D simulation modelling in FlexSim is a promising means of preliminary detection of bottlenecks, queues, downtime, resource imbalances, and risks of disrupting the rhythm of warehouse operations without interfering with the real infrastructure of the warehouse.

Conclusions

The study theoretically substantiated the possibilities of using FlexSim for 3D modelling of warehouse logistics, optimisation of warehouse processes, and support for resource management. It was established that the warehouse system should be considered as an operational chain in which the reception, placement, replenishment of selection zones, acquisition, packaging, shipment, and control of stocks are interconnected through material flows, personnel, equipment, routes, queues, and service rules.

Systematisation of 3D modelling areas has shown that composition optimisation covers the spatial, process, and resource levels. The spatial level was estimated through the average storage capacity utilisation rate ⩾90% and peak capacity utilisation ⩾100%. The process level was specified after the time from product acceptance to placement <3.5 hours, the internal order processing cycle <3.36 hours, and the full order processing cycle <6 hours. The resource level was related to the selection and shipment performance of ⩾70 order lines/man-hour, the share of overtime hours <1.88%, the average waiting time, the maximum queue length, and the level of resource usage. Analysis of FlexSim's capabilities has shown that the value of a programme is determined not only by 3D visualisation, but also by a combination of object, process, resource, and analytical modelling levels.

The 3D Layout, process Flow, A* Navigator, Rack and Storage Logic, Task Executers, Statistics Collector, Experimenter, and Bottleneck Analysis tools provide simulations of routes, queues, resource loading, downtime, throughput, and scenario scheduling changes. The developed logic "warehouse process – element of the 3D model – resource – performance indicator – management decision" showed that FlexSim can be used for preliminary identification of bottlenecks, resource imbalances, and risks of disruption of the rhythm of warehouse operations. The prospects for further research are related to the practical testing of the proposed conceptual model on real warehouse facilities, construction of applied FlexSim models for different types of warehouses, comparison of alternative scenarios for product placement, routing, acquisition, and resource support, and integration of 3D simulation modelling with digital doubles, warehouse management systems and real-time data to increase the adaptability of logistics processes.

Acknowledgements
None.

Funding
The study was not funded.

Conflict of Interest
None.

References

[1] Abid, S., & Mhada, F.Z. (2021). Simulation optimisation methods applied in reverse logistics: A systematic review. *International Journal of Sustainable Engineering*, 14(6), 1463-1483. doi: 10.1080/19397038.2021.2003470.

[2] Aretoulaki, E., Ponis, S.T., Plakas, G., & Tzanetou, D. (2024). Discrete event simulation and Digital Twins in warehouse logistics: A bibliometric and content analysis-based systematic literature review. *International Journal of Computer Integrated Manufacturing*, 37(10-11), 1376-1403. doi: 10.1080/0951192x.2024.2314772.

[3] Berezhniak, I., Slipenkyy, E., Doroshchuk, V., & Soroka, V. (2025). Increase the efficiency of warehouse processes by modelling a service centre. *Central Ukrainian Scientific Bulletin Technical Sciences*, 1(11(42)), 272-279. doi: 10.32515/2664-262x.2025.11(42).1.272-279.

[4] Bottani, E., & Casella, G. (2024). Discrete-event simulation in logistics and supply chain management: A scientometric perspective. *Production & Manufacturing Research*, 12(1), article number 2415038. doi: 10.1080/21693277.2024.2415038.

[5] Cannava, L., Perotti, S., Najafi, B., & Rinaldi, F. (2025). A simulation-based approach to improve energy efficiency and environmental performance in warehouses: The case of IKEA. *IFAC-PapersOnLine*, 59(10), 799-804. doi: 10.1016/j.ifacol.2025.09.136.

[6] Coelho, F., Relvas, S., & Barbosa-Póvoa, A. (2020). Simulation-based decision support tool for in-house logistics: The basis for a digital twin. *Computers & Industrial Engineering*, 153, article number 107094. doi: 10.1016/j.cie.2020.107094.

[7] de Carvalho Paula, M., Carvalho, M.S., & Silva, E. (2025). Improving warehouse operations: Leveraging simulation for efficient layout design and process improvement in a picking by line operation. *Procedia Computer Science*, 263, 481-489. doi: 10.1016/j.procs.2025.07.058.

[8] De Vito, P., Battista, U., Bolognesi, A., & Sanfilippo, S. (2024). Multi-method approaches for simulation modelling of warehouse processes. In *Proceedings of the 14th international conference on simulation and modeling methodologies, technologies and applications* (pp. 305-312). Dijon: ScitePress. doi: 10.5220/0012771700003758.

[9] Di, H. (2024). Design and research of automated warehouse simulation platform based on virtual visualization framework. *PeerJ Computer Science*, 10, article number e1809. doi: 10.7717/peerj-cs.1809.

[10] Ebrahimi, A., Jeon, H.-W., & Jung, S.-Y. (2023). Improving energy consumption and order tardiness in picker-to-part warehouses with electric forklifts: A comparison of four evolutionary algorithms. *Sustainability*, 15(13), article number 10551. doi: 10.3390/su151310551.

[11] Ekren, B.Y. (2020). A multi-objective optimisation study for the design of an AVS/RS warehouse. *International Journal of Production Research*, 59(4), 1107-1126. doi: 10.1080/00207543.2020.1720927.

[12] Ferrari, A., Carlin, A., Rafele, C., & Zenezini, G. (2023). A method for developing and validating simulation models for automated storage and retrieval system digital twins. *International Journal of Advanced Manufacturing Technology*, 131(11), 5369-5382. doi: 10.1007/s00170-023-12660-y.

[13] FlexSim. (n.d.). *3D simulation modeling and analysis software*. Retrieved from https://www.flexsim.com.

[14] Füchtenhans, M., Glock, C.H., Grosse, E.H., & Zanoni, S. (2021). Using smart lighting systems to reduce energy costs in warehouses: A simulation study. *International Journal of Logistics Research and Applications*, 26(1), 77-95. doi: 10.1080/13675567.2021.1937967.

[15] Gao, G., Feng, Y., Zhang, Z., Wang, S., & Yang, Z. (2022). Integrating SLP with simulation to design and evaluate facility layout for industrial head lettuce production. *Annals of Operations Research*, 321(1-2), 209-240. doi: 10.1007/s10479-022-04893-z.

[16] Grznár, P., Krajčovič, M., Gola, A., Dulina, Ľ., Furmannová, B., Mozol, Š., Plinta, D., Burganová, N., Danilczuk, W., & Svitek, R. (2021). The use of a genetic algorithm for sorting warehouse optimisation. *Processes*, 9(7), article number 1197. doi: 10.3390/pr9071197.

[17] ISO 14001:2026: Environmental management systems – requirements with guidance for use. (2026). Retrieved form https://www.iso.org/standard/14001.

[18] ISO 22301:2019: Security and resilience – business continuity management systems – requirements. (2019). Retrieved from https://www.iso.org/standard/75106.html.

[19] ISO 28000:2022: Security and resilience – security management systems – requirements. (2022). Retrieved from https://www.iso.org/standard/79612.html.

[20] ISO 31000:2018: Risk management – guidelines. (2018). Retrieved from https://www.iso.org/standard/65694.html.

[21] ISO 9001:2015. Quality management systems – requirements. (2015). Retrieved from https://www.iso.org/standard/62085.html.

[22] ISO/IEC 25002:2024: Systems and software engineering – Systems and software Quality Requirements and Evaluation (SQuaRE) – quality model overview and usage. (2024). Retrieved from https://www.iso.org/standard/78175.html.

[23] ISO/IEC/IEEE 24765:2017: Systems and software engineering – vocabulary. (2017). Retrieved from https://www.iso.org/standard/71952.html.

[24] Jeon, H.-W., Ebrahimi, A., & Lee, G.-H. (2023). A simulation-based experimental design for analyzing energy consumption and order tardiness in warehousing systems. *Sustainability*, 15(20), article number 14891. doi: 10.3390/su152014891.

[25] Kallat, F., Pfrommer, J., Bessai, J., Rehof, J., & Meyer, A. (2021). Automatic building of a repository for component-based synthesis of warehouse simulation models. *Procedia CIRP*, 104, 1440-1445. doi: 10.1016/j.procir.2021.11.243.

[26] Kogler, C., & Maxera, P. (2025). A literature review of supply chain analyses integrating discrete simulation modelling and machine learning. *Journal of Simulation*, 20(1), 110-134. doi: 10.1080/17477778.2025.2500393.

[27] Kolesnyk, K., Khusnutdinov, M., Trochimczuk, R., & Artyshchuk, I. (2023). Simulation modeling of warehouse operations of a transport company. *Computer Design Systems Theory and Practice*, 5(1), 8-18. doi: 10.23939/cds2023.01.008.

[28] Lewicki, W., Niekurzak, M., & Wróbel, J. (2024). Development of a simulation model to improve the functioning of production processes using the FlexSim tool. *Applied Sciences*, 14(16), article number 6957. doi: 10.3390/app14166957.

[29] Li, Y., Zhang, R., & Jiang, D. (2022). Order-picking efficiency in e-commerce warehouses: A literature review. *Journal of Theoretical and Applied Electronic Commerce Research*, 17(4), 1812-1830. doi: 10.3390/jtaer17040091.

[30] Pawlak, S., Saternus, M., & Nowacki, K. (2025). Application of discrete event simulation in the analysis of electricity consumption in logistics processes. *Energies*, 18(17), article number 4580. doi: 10.3390/en18174580.

[31] Rizqi, Z.U., Chou, S., & Cahyo, W.N. (2024). A simulation-based digital twin for smart warehouse: Towards standardization. *Decision Analytics Journal*, 12, article number 100509. doi: 10.1016/j.dajour.2024.100509.

[32] Rymarczyk, P., Bogacki, S., Figura, C., Rutkowski, M., & Staliński, P. (2024). Optimizing order picking processes in warehouses: Strategies for efficient routing and clustering. *Journal of Modern Science*, 57(3), 467-484. doi: 10.13166/jms/191201.

[33] Silva, A.C., Santos, R., Senna, P.P., Borges, F.M., & Marques, C.M. (2026). Enhancing picking-by-line operations: A simulation-based approach. *International Journal of Advanced Manufacturing Technology*. doi: 10.1007/s00170-025-17177-0.

[34] Singbal, V., & Adil, G.K. (2023). Development of an open-source data-driven simulator for the unit-load multi-aisle automated storage and retrieval systems. *Journal of Simulation*, 18(2), 220-238. doi: 10.1080/17477778.2023.2202337.

[35] Warehousing Education and Research Council. (2025). *2025 DC Measures Report*. Retrieved from https://werc.org/page/ASSESS-DC_Measures.

[36] Winkelhaus, S., Zhang, M., Grosse, E.H., & Glock, C.H. (2022). Hybrid order picking: A simulation model of a joint manual and autonomous order picking system. *Computers & Industrial Engineering*, 167, article number 107981. doi: 10.1016/j.cie.2022.107981.

[37] Yu, C., Liao, W., & Zu, L. (2023). Dynamic scheduling optimization method for multi-AGV-based intelligent warehouse considering bidirectional channel. *Systems*, 12(1), article number 9. doi: 10.3390/systems12010009.

[38] Žagar, A., Motaln, M., Belšak, A., Jerman, B., Ting, C., & Lerher, T. (2025). A simulation model of automated storage and retrieval systems for long and heavy loads. *Applied Sciences*, 16(1), article number 248. doi: 10.3390/app16010248.

[39] 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, article number 102921. doi: 10.1016/j.simpat.2024.102921.

3D моделювання складської логістики в програмному забезпеченні FlexSim: оптимізація логістичних процесів та управління ресурсами

Євгеній Сліпенький

Магістр, старший викладач
Національний університет водного господарства та природокористування
33028, вул. Соборна, 11, м. Рівне, Україна
https://orcid.org/0009-0001-7538-9642

Анотація. Мета дослідження полягала в теоретичному обґрунтуванні потенціалу програмного забезпечення FlexSim для тривимірного моделювання складської логістики, удосконалення складських процесів і забезпечення аналітичної підтримки управління ресурсами в складських логістичних системах. Дослідження мало теоретико-аналітичний характер і ґрунтувалося на систематизації структурних компонентів складу, напрямів тривимірного моделювання, функціональних можливостей FlexSim та методів ресурсного балансування. Результати показали, що склад доцільно розглядати не як статичний простір для зберігання товарів, а як процесну систему, у якій приймання, ідентифікація вантажів, розміщення, поповнення зон відбору, комплектування, внутрішньоскладське транспортування, пакування, відвантаження та контроль запасів утворюють єдиний операційний ланцюг. Встановлено, що тривимірна модель у FlexSim має поєднувати фізичні компоненти складу – зони, стелажі, маршрути, робочі станції, техніку, конвеєри й автоматизовані транспортні засоби – з логічними компонентами: чергами, буферами, правилами маршрутизації, пріоритетами обслуговування та режимами використання ресурсів. Систематизація напрямів 3D-моделювання засвідчила, що оптимізація складських процесів формується на просторовому, процесному та ресурсному рівнях. Просторовий рівень оцінено через середній рівень використання складської місткості ⩾90 % і пікове використання місткості ⩾100 %; процесний рівень – через час від приймання товару до його розміщення <3.5 год, внутрішній цикл обробки замовлення <3.36 год і повний цикл обробки замовлення <6 год; ресурсний рівень – через продуктивність відбору й відвантаження ⩾70 рядків замовлень/людино-год, частку понаднормових годин <1.88 %, середній час очікування, максимальну довжину черги та рівень використання ресурсів. Практичне значення дослідження полягає у формуванні інтегральної концептуальної моделі, цінної для логістичних менеджерів, керівників складів та аналітиків ланцюгів постачання, оскільки вона дає змогу попередньо виявляти вузькі місця, черги, простої, ресурсні дисбаланси й ризики порушення ритмічності складських операцій

Ключові слова: матеріальні потоки; операційний ланцюг; пропускна здатність; вузькі місця; комплектування замовлень