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Simulations in planning logistics processes as a tool of decision-making in manufacturing companies

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Abstract
Appropriate logistics planning is a key factor influencing the quality and efficiency of processes in manufacturing companies. Logistics planning can be defined as the process of making significant decisions (concerning both logistics processes and resources) for the functioning of an organization. It is a process consisting of stages in which important decisions are made regarding the optimization of all activities of the company, including in the field of: production, supply, sales, distribution, transport. The main goal of logistics activities is to minimize the operating costs incurred, as well as to better manage human resources. The main aim of the article is to present the legitimacy of using selected simulation software as an actual tool in making logistic decisions in the field of order picking system (OPS) based on a case study. For research purposes, a model was prepared in FlexSim and there were applied S-shape and Return routing methods. Based on simulation results, an analysis of the selected process was carried out. The obtained results indicate possible directions of changes and allow to make the right decision in the field of planning logistics processes.

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1. Introduction

Logistics planning is one of the key elements of the functioning of modern enterprises. Business entities that do not pay attention to this part of managing their activities cannot succeed in today's market realities. Logistics planning in a company has a specific goal set in advance, which may be to increase income, reduce costs, shorten delivery times, etc. (Mozos and López 2020). In fact, logistic planning is inherently related to making decisions regarding the optimization of a company's activities in the areas of supply, production, sales, distribution or reverse logistics. (Simchi-Levi et al., 2010; Fink and Benz 2019). Better use of human, material and non-material resources is the main direction of the undertaken logistic activities. As a result, it is possible to reduce operating costs and increase profit, but also to make processes more flexible or shorten their duration. Logistics planning is a complex problem that requires many analyzes of the processes already in progress or planned, resources and potential resources, and costs that will be incurred. Today's intelligent solutions make it possible to precisely plan virtually every process in the company, starting from the most important ones from the point of view of the added value they bring, and ending with less important processes, but necessary for the functioning of the company. Many authors indicate that IT (information technology) makes the supply chain more reliable, load-resistant and at the same time efficient (Tseng et al., 2011; Milewska 2017; Mesjasz-Lech 2014; Daroń, Wilk 2020). However, IT solutions used by market entities differ, e.g. in terms of their scope (they may include all departments and processes or only some of them), but also their purpose - they facilitate running a business, cooperation with partners and clients, planning new activities, projects or improvements to already implemented processes.

Nowadays, there is common to use such solutions as: Big Data, analytical - research tools, Business Intelligence, Internet of Things (IoT), Cloud Computing, the so-called Deep Tech (Machine Learning, Artificial Intelligence, Artificial Neural Network, blockchain), Virtual / Augmented Reality, programming and developing tools, SCM (Supply Chain Management), CRM (Customer Relationship Management), ERP (Enterprise Recourse Planning) tools or telematics. However, attention is drawn to the significant role of the use of simulation programs in business planning, including logistics planning. Interesting research was presented by Coelho et al., (2021), according to which more than 30% of scientific articles in the field of internal logistics use simulation as a decision-making tool in this area. Currently used simulation programs allow not only to map the environment and its surroundings and to make a visual presentation of objects and physical means, but also to map the complex logic of the entire system functioning. Thanks to this, companies receive support for the decision-making process at all stages of management - both in the design phase of logistics activities and during their duration - in order to optimize processes or adapt to changing market conditions and the needs of the company.

Therefore, in this article, it was decided to focus on this IT applications regarding to planning logistics processes. The main aim of the article is to present the legitimacy of using selected simulation software as an actual tool in making logistic decisions in the field of order picking system (OPS) based on a case study. There are many studies on OPS in the scientific literature. However, researchers usually focus on one selected factor influencing the OPS (Bottani et al., 2019; Ho and Lin 2017; Parikh and Meller 2010; Winkelhaus 2022, etc.), e.g. warehouse layout, also in terms of the amount of storage, allocation of storage places, picking or routing system. On the other hand, the analysis carried out for the purpose of this article allows to present the benefits of using simulation to shape both the size/layout of a warehouse, as well as selected OPS methods. Thus, it relates to both - the tactical and operational level of the picking process management.

2. Literature review

2.1. Simulation role in logistics processes

Simulation is an imitation, an imitation of some real process, usually with the help of experiments carried out on a model representing this process (Beaverstock et al., 2011). Simulations have been widely used in modeling logistics processes. It is considered a standard approach to assessing the performance of logistics systems (Fanti et al., 2014; Ramstedt and Woxenius 2006; Steenken et al., 2004) due to the inherent ability to deal with the complexity and randomness of logistics operations. Simulations are possible by virtualizing processes with tools, testing virtual models before applying them in the real world, and they allow (Agalianos et al., 2020; Gunal 2019):

- predict the efficiency of logistics systems, possible delays or the appearance of bottlenecks,
- analyze the interaction of various components of the logistics system,
- evaluate alternative scenarios,
- support decision making.

This is well known that poor process design directly makes them uneconomical (Kiran, 2020; Baskiewicz, 2018). Whereas, the use of the possibility of designing a logistics process, or any other, by creating a model and simulating its operation using IT solutions, undoubtedly reduces the risk associated with this wastefulness. In general, the benefits of simulation applications can be divided into four categories: feasibility, cost avoidance, detail design and activities or operations (Beaverstock et al., 2017). In the light of the above, it can be said that simulations are inherently related to the optimization of processes. Optimizing the process by simulation, on the other hand, means building a model that reflects the process and finding the best configuration of input fields that find the best response value (Krynke, 2021).

Also Kaczmar (2019) indicates the wide application of simulation in the area of logistics. He notices that the simulations used in logistics can be divided into five most important areas, such as: customer service, logistics planning, warehouse management, material flow management and inventory management, which is confirmed by numerous publications in these areas (Bajdor, 2021; Setamanit, 2018; Hameri and Paatela, 1995; Moussa et al., 2019; Kallat et al., 2021; Bley et al., 2000; Sridhar et al., 2021).

It should be noted, however, that many companies, especially smaller ones, do not use simulation when shaping logistics processes due to the high costs associated with the purchase and maintenance of commercial simulation tools. (Lang et al., 2021). On the other hand, there are a large number of simulation programs that are free, and some companies provide demo versions that guarantee temporary access to the resource or a truncated version of it, e.i. FlexSim, Arena™ Simulation Software, AnyLogic, Simul8, SimCAD Simulation Software, or Tecnomatix Plant Simulation. The common point of the presented solutions is the visualization that allows to design the layout of a given space in which the process is carried out and the possibility of simulating with the analysis of the results of the efficiency and use of model objects. As research shows (Lang et al., 2021), free software for simulating logistics activities can be an alternative to commercial tools for solving typical planning tasks in production and logistics. However, a certain difficulty for Polish users may be the use of the English language in the software, in which tutorials are also prepared.

2.2. Picking order system in simulation

Developing and applying simulations to designing warehouse processes is very demanding task. Especially in large and complex storage systems, numerous problems arise in design and control. As noted by numerous researchers, the configuration of the system is often complicated due to the large number of varieties of products requiring storage, significant fluctuations in demand and the areas of required warehouse space (Kusiak, 2000; Güller and Hegmanns, 2014). Therefore, there are so many publications in the field of modeling warehouse processes, in particular concerning OPS. For example, only in the Science Direct database, when searching for publications containing the words: warehouse, picking and simulation, we can find about 1,750 studies dated from 2014. In the same time period, publications using, e.g. Arena software, account for about 7% of this amount, while those using software FlexSim - 2%. Research shows (Berg and Zijm, 1999; Guimaraes et al., 2022; Koster et al., 2007) that the picking process is mentioned as one of the most expensive and labor-intensive activities in warehouses, consuming up to 55% of the total costs of their operation.

Order picking is defined as the process of picking products from stock to meet specific customer requests (Chen et al., 2010; de Koster, 1994; Petersen and Aase 2004). In the research literature, there are many studies on this area and, as it can be seen, it is still an inexhaustible topic. At the same time, it should be noted that planning the OPS usually involves dealing with problems at the tactical and operational level (van Gils et al., 2018, de Koster et al., 2007). Tactical problems include: zone location and assignment (Francis, 1967; Celk and Süral 2014; de Koster et al., 2012; etc.), storage location assignment (Bottani et al., 2012; Bottani et al., 2019; Muppani and Adil, 2008 etc.), zone picking (Koo, 2009; Ho and Lin, 2017; Quader and Castillo-Villar, 2016 etc.) and order consolidation and sorting (Chabot et al., 2018; Tan et al., 2021; Boysen et al., 2018 etc.). On the other hand, operational problems include: batching (Jiang et al., 2022; Ho et al., 2008; Li et al., 2016 etc.), routing (Caron et al., 1998; Chackelson et al., 2013; Weidinger et al., 2019 or van Gils et al., 2018), workforce allocation and level (Vanheusden et al., 2020; Grosse and Glock, 2015; Sainathuni, 2014 etc.) and job assignment (Rubrico, 2011; Matusiak et al., 2017 etc.). Thus, the picking process is a complex topic, still inexhaustible, and undoubtedly affects the customer service process (Kawczyński and Aguilar-Sommar, 2006), which is related to the effectiveness of the entire supply chain.

For the purposes of this article, the route planning methods used in the research part should be additionally discussed. Due to the planned warehouse area including block storage, 2 methods were selected for analysis: the S-Shape picking method and the Return picking method.

The S-Shape picking method is the most popular (Masae et al., 2021; Guimarães et al., 2022;) and a simple method of determining the picking route, in which the contractor of the task (picking) moves between the racks along a route resembling the letter S. After collecting parts from a given aisle, the operator goes to its end and turns to the next aisle, collecting subsequent parts from it, but does not enter the aisle, where there are no items to be picked up. Research (Hong and Kim, 2017) concludes that the grouping of orders with an S-shaped route reduces the travel distance by an average of 10-15% compared to the grouping of orders with a two-way route when orders are batching using the saving algorithm in eight-aisle OPS. However, in this system it is necessary to have transport routes at the head and the end of the racks.

In turn, the Return picking method (also U-turn picking method) is the second most often discussed in the literature and used in practice (Manzini et al., 2007; Theys et al., 2010; Wilkenhaus et al., 2022 etc.). In this case, the picking job contractor enters each aisle that has items in the order list until it picks up all the required items, then returns to the main aisle and continues picking items from the next aisles.

3. Methodology and assumptions

It was decided to analyze the selected logistics process (picking route) using one of the available programs – FlexSim Version 21.1.5). In the first step, a model was designed that included objects from the Fixed resources library, such as Source, Queue, Racks, Combiner, and from the Task Executers sub-library - Transporter.

It is assumed that the company will use manual forklift with battery drive. The dimensions of the transporter are: 1720 mm (total length) x 777 mm (width). The transporter is characterized by the possibility of raising the mast to a height of 1600 mm, which means that this parameter meets the technical requirements, as the storage will take place on low-storage racks - up to 2 m high. Depending on the method used in OPS, the warehouse size will change (Fig. 1 and 2), which results from the Polish Standards PN-M-78010: 1968 (Internal transport - Roads and door openings. Design guidelines), but dimensions of the racks will be the same (Fig.3).

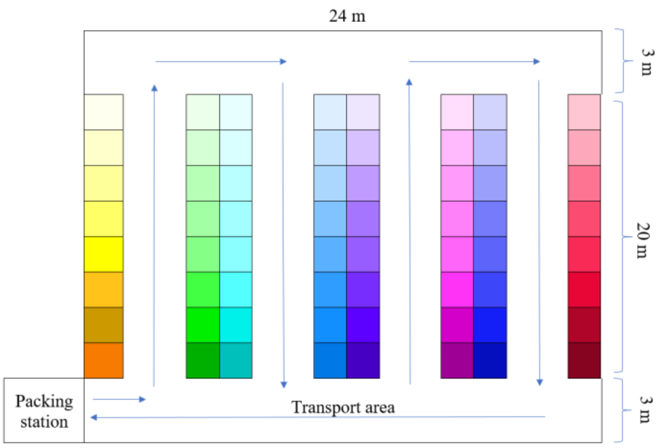

Fig. 1. Warehouse area for S-shape picking method

In the case of the S-shape method, the transport routes in the aisles between the racks should be designed for two-way traffic, because skipping the aisle with no items to be picked up by the transporter and going to the next one, may cause a collision course with the next conveyor. This means that the minimum road width designed only for motorized means of transport without pedestrian traffic is:

$$b = 2a + 90, \quad (1)$$

where a is the width of a person with a load or the width of the transport vehicle, and b - width of the transport road in cm.

Therefore, taking into account the dimensions of the transport trolley and the load exchange, which can protrude beyond the transporter to a maximum width of 1 m, it was established that the width of the road between the racks would be equal to 3.0 m. The main transport route leading to the packing station must meet the same condition as to width. Therefore, in the S-shape method, the warehouse area next to the racks, in which 8 racks with the dimensions shown in Fig. 3 are located, is 24 m x 26 m (Fig. 1).

In the case of the Return picking method, the transport routes will have the same width (they allow the transporter to be turned back), however, there is no need to design an additional transport route at the back of the racks (Fig. 2).

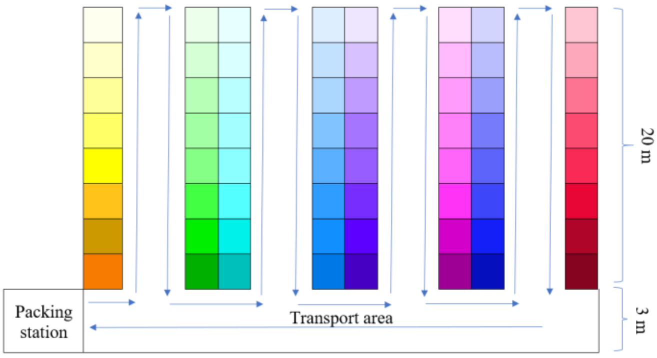

Fig. 2. Warehouse area for Return picking method

This means that the warehouse area can be reduced or used for additional storage spaces.

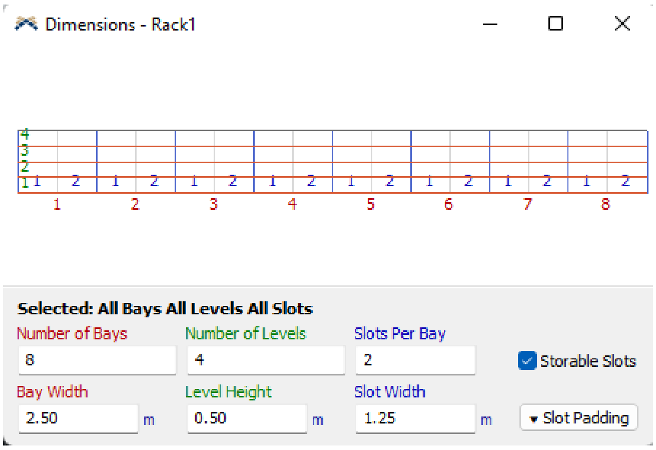

Fig. 3. Racks dimentions

In the model, there are generated 100 types of products that appear according to a discrete homogeneous distribution (with the same probability). These elements appear at the same time due to the fact that the simulation concerns the warehouse area itself and the planning of picking routes. So they are available all the time. The products are grouped into 8 classes and stored on 8 shelves. Fig. 4 shows the arrangement of objects in the model.

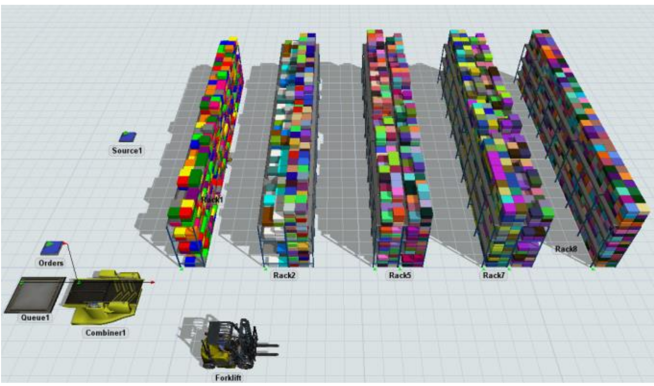

Fig. 4. Warehouse area

In the model it was used the so-called item list, which reflects the operation of a WMS (Warehouse Management System) and allows to quickly locate items to be picked up from the warehouse by the transporter. In the next step, the times of appearance of 75 orders were programmed using the Arrival Schedule function (Fig. 5) on the Orders object (another Source).

Arrivals - Orders

Arrivals 75 Labels 1

	ArrivalTime	ItemName	Quantity	Type
Arrival1	0	O1	1	1
Arrival2	60	O2	1	2
Arrival3	120	O3	1	3
Arrival4	180	O4	1	4
Arrival5	240	O5	1	5
Arrival6	300	O6	1	6
Arrival7	900	O7	1	7
Arrival8	1140	O8	1	8
Arrival9	1260	O9	1	9

Fig. 5. Schedule of orders

Next step was a creation a global table containing an example component list, which is used in the simulation model by the Combiner object that maps the packing station. It contains 75 ordered orders, in which there are from 1 to 12 types of products. Thus, a Trigger of the On Entry type was set on the combiner object, which included a reference to the list of orders (Fig. 6).

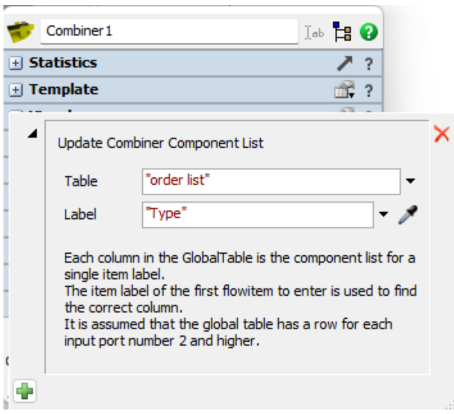

Fig. 6. Reference to the component list

An additional global table was also created, in which selected parameters of the transporter were modeled. Exemplary values of these parameters are shown in Fig. 7.

	Col 1
Max Content	4
load time	exponential(5,1);
unload time	exponential(2,1);
max speed	2
acceleration	1
lift speed	0.13
deceleration	1

Fig. 7. Transporter variable parameters in the model

The Max Content parameter refers to the number of products that can be simultaneously transported by the transporter, which affects the number of trips that must be made to complete the order. On the other hand, load time and unload time were modeled as an exponential distribution with a variable successively 5 and 2 seconds and allocation 1.

In the last step, the paths of the forklift were planned using nodes - Network Nodes in accordance with 1 of 2 route planning methods for the completion process:

1. The S-Shape picking method
2. The Return picking method.

Thus, two models were created representing the warehouse area and the picking process, differing in transport routes.

4. Results and discussion

4.1. The S-Shape picking method

The designed warehouse layout, along with the marked direction of the transporter's movement in accordance with the S-Shape picking method, is presented in Fig. 2.

In total, 9 Network Nodes were plotted in this method, modeling the routes in accordance with the assumed method of movement, as shown in Fig. 8.

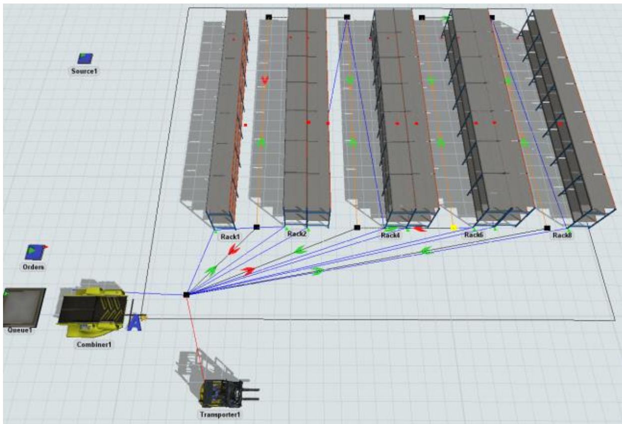

Fig. 8. Network Nodes in S-Shape picking method model

An important task here is to accurately indicate the virtual distance between nodes, which maps the real distances in the warehouse (Fig. 9), as well as the flow directions taking into account route changes in the case of not collecting elements, e.g. from the first aisle. In the model, blocked flow directions are marked with a red arrow on the routes between nodes. During designing the flow, a connection with the keyboard D key was additionally used, which eliminated unnecessary returns of the transporter to the initial nodes in the aisles and blocked the return directions so that the passage was unidirectional. The elements (products) are taken from the racks by forklift and transported to the packing station at the Combiner facility. After packing, the finished order is transferred to the buffer (Queue object), which is the last element in the presented model.

In this method, the conveyor can pick up items from the racks on both sides of the aisle.

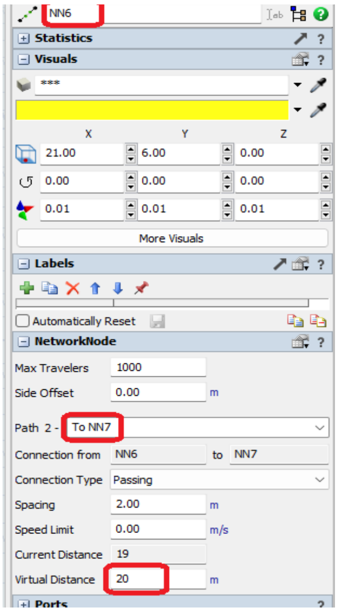

Fig. 9. Virtual distance settings in S-shape method

After running the simulation and checking the correct operation of the model, selected statistics, presented in the following section, were created.

4.2. The return picking method

In the next step, the process was remodeled so that the paths of the transporter follow the flow according to the return picking method (Fig. 10). Preexisting Network Nodes have been removed and new ones have been programmed to follow the flow philosophy.

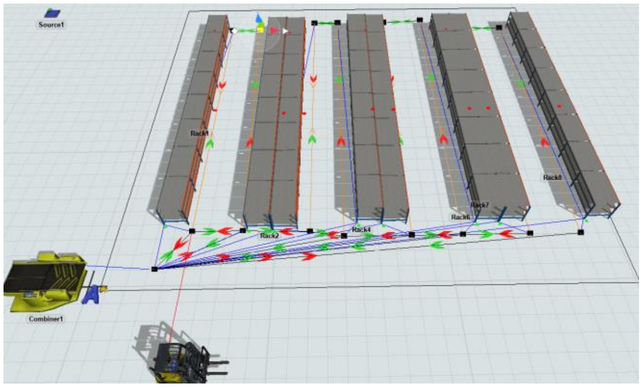

Fig. 10. Network Nodes in Return picking method model

In this case, it was much more than Network Nodes (17) due to the requirement for the transporter to download elements located only on the left side in relation to the direction of travel. Thus, the conveyor can pick up elements only from the racks located on one side of the aisle and the route of each of them goes in both directions. The component list on the packing machine (Combiner) and other model parameters remain the same. After the correctness of the model operation was verified, the simulation was run and the statistics were verified.

4.3. Comparison of the base results of the model for both methods

The model analysis in terms of the order picking system was started with the initial settings for both methods, which are presented in Table 1. It was assumed, inter alia, that the transporter can carry only two transport units at a time.

Table 1. Parameters for basic model

Max Content	2 pcs
load time	exponential(5,1)
unload time	exponential(2,1)
max speed	1 [m/sec]
acceleration	1 [m/sec]
deceleration	1 [m/sec]
lift speed	0.13 [m/sec]

When analyzing the work of the transporter in both methods, it can be stated that it is largely unused - the idle state in the case of S-shape is at a level exceeding almost 49%, while in the case of the Return method - almost 45%. On the other hand, the activity of transporting the load takes the longest in both cases.

Table 2. Results for basic model

	S-shape route	Return route	unit
Average Staytime	52.31	59.32	sec
Min Staytime	7.50	14.56	sec
Max Staytime	168.53	156.56	sec
Travel empty	14.26	17.06	%
Travel loaded	30.13	31.65	%
Loading	4.84	4.84	%
Unloading	1.94	1.94	%
Idle	48.83	44.48	%
Travel distance	12480	13765	m

Comparing the same statistics for both types of goods picking, it can be shown that the percentage distribution of the individual stocks for the transporter is basically very similar. However, there is a big difference in the distance traveled - in the case of the S-shape method, the distance is shorter by over 1 km. The carrier occupancy distributions for both methods were also compared (Figs. 11 and 12).

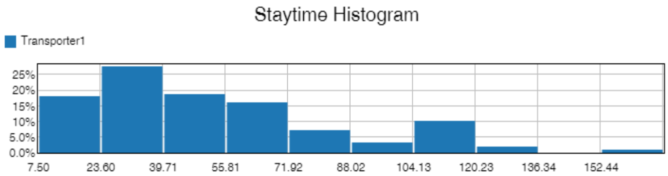

Fig. 11. Staytime histogram for S-shape method

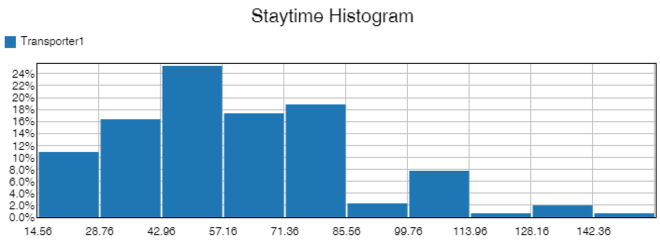

Fig. 12. Staytime histogram for Return method

The results show that in the case of S-shape the routes lasting between 23.60 sec and 39.71 sec were most common (over 25%), while in the Return method over 24% routes were those lasting from 42.96-57.16 sec.

4.4 Comparison of experiments results

In the next step, it was investigated what the results will be in the case of increasing the maximum speed of the trolley moving through the warehouse. Max speed was set at 2m / sec, which is just over 7 km / h. Of course, the distance traveled in both methods will not change, but you can expect differences in the workload of the transporter. The results of the experiment are presented in Table 3.

Table 3. Results for higher speed

	S-shape route	Return route	unit
Average Staytime	29.83	33.16	sec
Min Staytime	5.50	9.03	sec
Max Staytime	91.02	85.02	sec
Travel empty	7.94	3.34	%
Travel loaded	15.84	16.43	%
Loading	4.84	4.84	%
Unloading	1.94	1.94	%
Idle	69.44	67.43	%
Travel distance	12480	13765	m

In this case, the percentage of the transporter idle increases significantly from 45% to 69% for the S-shape method and from 49% to 67% in the Return method.

The average time of a single picking route has also dropped spectacularly. It was 22 seconds in the S-shape method and 26 seconds in the Return method, respectively.

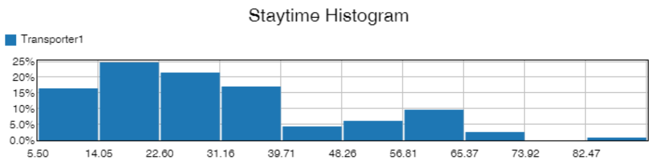

Fig. 13. Staytime histogram for S-shape method with higher max speed

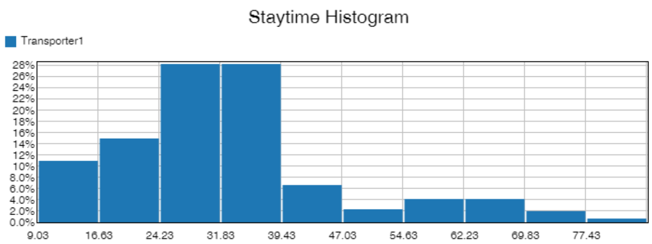

Fig. 14. Staytime histogram for Return method with higher max speed

When analyzing the histograms for both methods with changed parameters, a clear shift to the left was observed, which meant a reduction in the time of the most frequently recorded picking route times.

It was also decided to investigate the impact of increasing the number of simultaneously transported items of products on the efficiency of the transporter and the distance covered. When analyzing the list of orders, it was observed that the number of ordered products does not exceed 6 packages. Therefore, it was also decided to take this parameter into account by setting the capacity (max content) of the transporter to 6. The speed was left at the base level - that is 1m / sec (about 3.5 km / h). The results are presented in Table 4.

Table 4. Results with transporter max content equals 6

	S-shape route	Return route	unit
Average Staytime	89.49	98.50	sec
Min Staytime	27.50	10.50	sec
Max Staytime	78.05	335.40	sec
Travel empty	6.01	4.94	%
Travel loaded	24.44	28.65	%
Loading	4.84	4.84	%
Unloading	1.94	1.94	%
Idle	62.75	59.63	%
Travel distance	8599	9443	m

In this case, the average route time in the S-shape method increased in relation to the basic parameters of the model by 37 seconds (which gives over a 70% increase in this value) and in the Return method by 38 seconds (an increase over 64%). However, the benefits can be seen when the transporter is used. The idle state in this case is almost 63% for the S-shape method and almost 60% for the Return method. Which means that your equipment can be used in additional warehouse activities. Moreover, the distance covered in both methods decreased significantly. In both the S-shape and the Return method, the change in distance was about 4 km, which is about a 30% reduction in the length of the route.

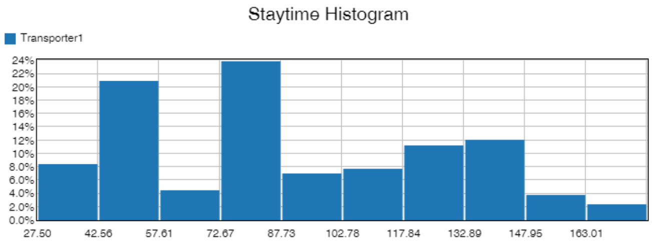

Fig. 15. Staytime histogram for S-shape method with higher transporter capacity

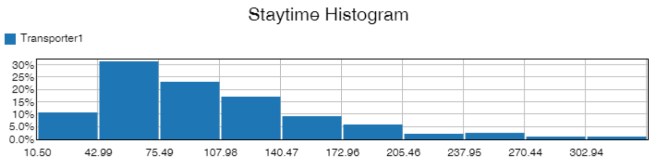

Fig. 16. Staytime histogram for Return method with higher transporter capacity

In the case of technical possibilities allowing for the simultaneous transport of 6 transport units, the results of the staytime histogram analysis (Figs. 15 and 16) show further differences in relation to the base version of the model. In the S-shape method, routes with a duration between 72.67 and 87.73 seconds were the most common (24%), while in the case of the Return method, the distribution of the duration of the loading operations indicates that most often (30% of cases) the duration of the picking route was recorded at the level between 42.99 s 75.49 seconds.

5. Summary and conclusion

The main goal set out in this article, which was to present the legitimacy of using simulation software in making optimization decisions related to shaping both the size and distribution of the warehouse, as well as selected methods of picking order system, was achieved by building a model in the FlexSim environment and using two selected methods picking (S-Shape and Return picking method). The analysis of the statistics available in the selected simulation program regarding the Transporter utilization status and the number of orders that can be completed leads to the choice of the picking method, pointing to the S-shape method as more effective. For example, in the base model Average Staytime is approx. 12% lower in the S-shape method than in the Return method, while in the model with a higher maximum speed, the same parameter decreases by 10%, and in the model allowing the transport of 6 parcels at the same time - 9%. These results are consistent with the research of other authors (Hong and Kim 2017).

The obtained results undoubtedly make it possible to make a decision in terms of planning this logistic process and indicate possible directions of changes. For example, the presented model assumes that the picking process is carried out by 1 contractor - a transporter, whose picking time for all items on the list of components is longer than the time of the packing process at the Combiner facility.

Thus, all in all, computer modeling and simulations are a useful logistical planning tool that allows you to minimize the operating costs incurred. Moreover, the article presents available IT solutions enabling the construction of virtual models and simulations for better logistics planning, indicating that most of them provide free demo versions useful for less complex logistics processes.

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作为制造公司决策工具的物流流程规划模拟

關鍵詞
做决定
管理
物流流程
模拟
挑选路线

摘要
适当的物流规划是影响制造公司流程质量和效率的关键因素。物流规划可以定义为为组织的运作做出重大决策（涉及物流流程和资源）的过程。这是一个由多个阶段组成的过程，在这些阶段中，就优化公司的所有活动做出重要决策，包括在以下领域：生产、供应、销售、分销、运输。物流活动的主要目标是最大限度地降低运营成本，以及更好地管理人力资源。本文的主要目的是基于案例研究，展示使用选定的仿真软件作为在订单拣选系统 (OPS) 领域做出物流决策的实际工具的合法性。出于研究目的，在 FlexSim 中准备了一个模型，并应用了 S 形和返回路由方法。 根据仿真结果， 对所选工艺进行了分析。获得的结果表明了可能的变化方向，并允许在规划物流流程领域做出正确的决定。