

ANALYSIS OF TRANSPORT NETWORK PERFORMANCE USING SIMULATION TOOLS

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Purpose: The paper presents the results of the analysis of the transport network performance using simulation methods and tools.

Design/methodology/approach: The transport network was modeled using FlexSim computer software. The analysis involved creating two simulation models of the conveyor network. The first, or baseline, model was based on non-accumulating conveyor technology at workstations, while the second model included accumulating conveyors.

Findings: Modeling transportation networks using computer software allowed us to design and select the most optimal transportation system for the company. Simulation studies showed that changes introduced to the baseline model improved system performance, increasing the number of filled order bins by approximately 67%, without significantly increasing warehouse space.

Originality/value: Simulation tools enable the proper structure of a conveyor system to be determined at the design stage, allowing for accurate performance and cost estimation, as well as for system refinement before installation in real-world conditions.

Keywords: computer simulations, modeling, FlexSim, performance improvement, transportation networks.

Category of the paper: Case study.

1. Introduction

Developing an effective conveyor network model is essential to streamline logistics processes. In this paper, the so-called basic conveyor network model and the improved model were analyzed. The work included creating a technical flow diagram within the conveyor network, followed by a simulation model in FlexSim. The result was a fully functional simulated model, which was then subjected to qualitative and cost evaluation in the final analysis. According to researchers in the field, designing conveyor networks involves choosing the layout of the lines, controlling material flow, and minimizing energy consumption (Susanto

et al., 2020). Analysis of results presented in the literature shows that designing an efficient transport network requires combining precise flow models (Suchorab-Matuszewska et al., 2025; Mallah et al., 2023) with optimal belt speed control (Pihnastyi et al., 2023; Suchorab-Matuszewska et al., 2025 and energy management with the network of routes and storage levels (Kawalec et al., 2020). Key factors ensuring optimal performance include a high fill rate, proper drive configuration, large buffer tanks, and advanced routing and control algorithms. One of the main tools in designing and optimizing conveyor transport systems is simulation methods. They allow testing designed systems, identifying so-called bottlenecks, and adjusting operational parameters without interfering with actual operations (Bobinics, Marasova, 2025; Hrnickova et al., 2025; Husar et al., 2024; Lilja, Olsson, 2019; Szntesi, Tamas, 2023).

2. Description of the conveyor transport network system

The subject of the analysis in this study is a conveyor network serving as a storage and component picking system for production purposes. This system is the so-called automated Person-To-Good picking method (the employee collects specified quantities of goods), which involves placing the conveyor network in a shelving storage area and positioning flow racks above the conveyor. The operator managing the picking station waits for the arrival of a container with an order, then collects the appropriate quantity of components into the production container and confirms the picking. When the container stops at the station, LEDs controlled by the pick-by-light system illuminate the locations from which the operator is to pick a specified number of components. From the pick-by-light screen, the operator reads how many units of a given component need to be taken and placed into the production container. The action is confirmed by pressing a button on the location screen. When the system receives confirmation that all components have been collected at the assembly station, it automatically replaces the assembly container.

The system is divided into two storage methods: flow racks and shelves. In the flow rack section, production components that are picked most frequently are stored, so they are located closest to the picking station. The other storage method is shelves, which are located behind the operator. The shelves hold items with medium and low turnover.

To design a fully functional logistics model, in addition to the picking area, the following zones are also considered:

- order start – the zone where the container is generated and the order is assigned to the container by scanning at the loop entry,
- decanting – the process of repackaging items into plastic containers handled by automation,

- flow channels – this is the storage area for the fastest-moving items, which the operator has direct access to,
- shelves – the zone where the operator manually picks items from standard shelves, the downloaded items are classified as medium and slow-moving items.

3. Methodology

Simulation methods were used to analyze the efficiency of transported cargo units. In the simulation software, a logistics installation designed to support the component picking process for production was modeled. For research purposes, the FlexSim software was chosen due to its lower level of technical complexity compared to other programs of this type. Other programs that allow the construction of an identical research model require a good knowledge of programming languages. FlexSim, in terms of functionality, is not inferior to more advanced programs, but it allows simulation models to be built in a simplified way. The simplicity of this program lies in pre-defined simulation objects, which already contain programmed functionalities that can be modified through the user panel. FlexSim software is more oriented toward ease of use when creating models (FlexSim, 2017). Due to its license-related limitations, FlexSim software allowed for setting up a maximum of 100 objects in the simulation model. This limitation resulted in certain less significant processes, which do not considerably affect the performance of the entire installation, being generalized. Generalization involved representing several interacting objects in the real model with a single object in the simulation software. The introduction of generalization, that is, reducing the number of objects, did not affect the results of the present study, as the objects still performed their function, while their visualization was simplified.

After building the baseline model of the logistics installation in FlexSim software, all parameters defining the operation of the objects within the logistics model were modified. A key aspect was determining the cycle times of individual activities or tasks, that is, how long a given container would be handled during order picking, or specifying the time intervals, known as takt time, i.e., how often a given container would be released to the installation. The release takt time was calculated based on the assembled mass.

The next step was the experimental phase, in which the efficiency of the installation was examined for different takt times and process cycles. Two variants were analyzed:

- the number of containers with assembled components that left the installation within an hour, a shift, and a full day,
- the number of containers that were sent as replenishment to picking locations, also within an hour, a shift, and a full day. After the experimental phase, which allowed the identification of system bottlenecks, the model was improved and the efficiency of the installation was re-examined for different cycle times and process cycles.

4. Designing the base model

The first step in building a model for simulation studies was creating a base with a conveyor system using Visio software. The base was then loaded into FlexSim software and scaled according to the dimensions given in Visio. The main goal was to keep the natural dimensions so that all the presented conveyor sections were represented at a 1:1 scale. A functional model of the transport conveyors is shown in Figure 1.

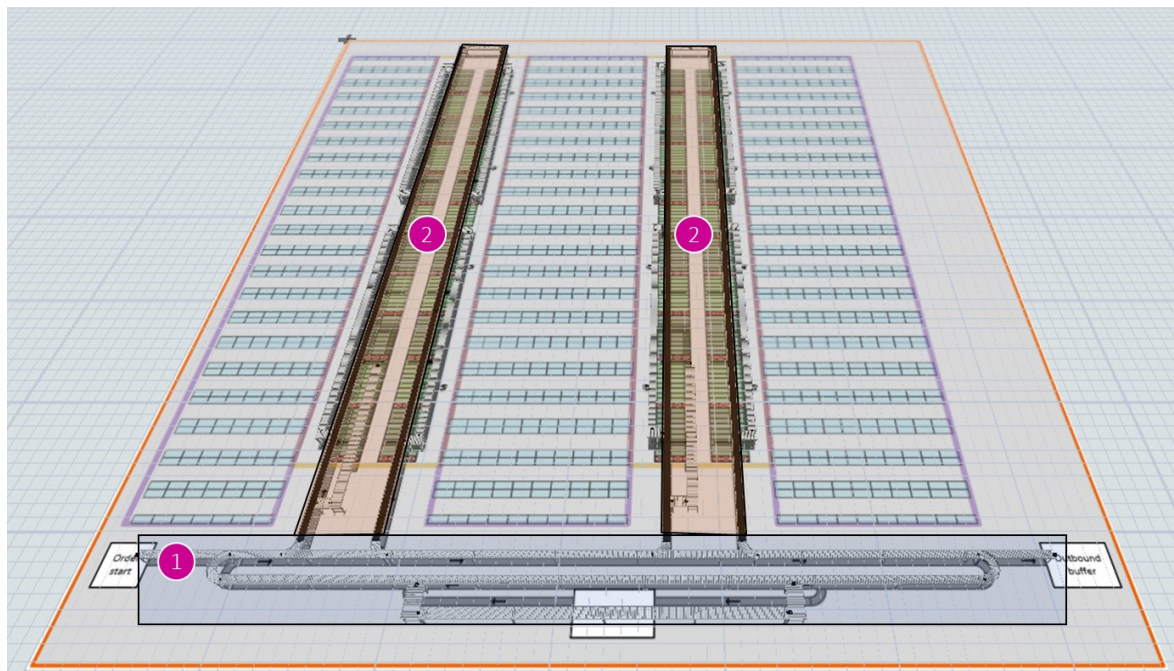


Figure 1. Conveyor system of the base model: 1 – main conveyor loop, the so-called conveyor highway responsible for distributing flow between functional zones, 2 – conveyors with flow racks.

Source: Own elaboration using the FlexSim program

The next step, after creating a complete network of conveyors, was to place fixed resources within the system. The main resource consists of containers, which represent actual flow within a real conveyor installation. Fixed resources in FlexSim software are not only elements that generate flow but also those that receive flow from the installation, in order to simulate a container exiting the installation, because in the real model a container, after completing all picking tasks in the installation, is directed to the exit. Typically, depending on the type of installation and its purpose, the exit for such a container may be directly to another department within the enterprise, e.g., production, or in the case of order picking for the end customer, these types of containers are directed to the palletization area, from where they are later transported to the loading gate. In this work, the installation is intended for assembling production components, so the transport takes place to the production area, where the final product is assembled from the aforementioned components. Inside the installation, there are several key elements that generate resources or, in the case of a sink, take resources from the installation.

One of the main elements is the "Order start" – the starting point where containers with orders are generated. Another main element of the model is the so-called sink, which is an object responsible for taking the flow out of the installation. If any material is put into the sink, it disappears from the conveyor installation and only exists in memory as a countable resource. The last key element that generates resources in the conveyor installation is an object responsible for simulating the generation of empty containers in the installation. Empty containers in the system are generated during the picking process because components are picked from containers used for storing materials, and as the process progresses, these containers get emptied. At that point, the picking station operator takes the empty container from the picking location and places it on the conveyor. The conveyor then transports these containers to the repacking station, where they are held until the repacking process starts.

To create flow logic, it was proposed to generate labels. In the FlexSim program, a label can be assigned to any resource at the moment of its creation or the label can be changed during the process. The third option is to set the so-called probability, in which percentage parameters are determined to specify the likelihood that a source will release a resource with a particular label. In the presented case, containers with two labels are generated. Each label has an equal probability of appearing, as it is distributed 50%/50%.

5. Identification of the causes of performance limitations of the modeled transport network system

To examine the performance of the described installation, certain operating parameters for the simulation model were created and the operating time was determined. Based on this, optimal parameters were identified, showing the maximum performance of the installation, meaning the flow that can be effectively handled by the system. When one unit has high performance and another has low performance, that unit becomes a bottleneck. Compiling all bottlenecks and device performances constitutes what is called system performance, which is the maximum capacity of the installation, determined by the limitations of the weakest elements.

As a result of analyzing the modeled transport system, the following bottlenecks were identified:

Intersection point at the order start and decanting loop – the intersection constitutes a bottleneck when other constraints cause flow disturbances. This means that the indicated case is not the main cause of limiting the plant's capacity but may be one of the potential points where flow can be halted if other bottlenecks lead to flow stoppage.

Non-accumulating conveyors - a limitation may occur when the system is loaded with too many containers. The interaction of transfer conveyors with non-accumulating conveyors can lead to downtime when the conveyors are overloaded. This is one of the potential downtimes that have a significant impact and may cause bottlenecks in less critical points by disrupting the flow continuity. Analysis indicates that non-accumulating conveyors significantly reduce the technical efficiency of the entire system and decrease the buffering potential of the installation.

Buffer before the repacking stations – if too many containers build up here because they can't be transferred to the picking station, the entire system will stop. Holding containers at this point has a big impact on the whole operation since it causes the main loop to get blocked, which stops the flow. If the simulated overload above isn't fixed by manually removing containers from the conveyor, it will lead to downtime for the entire system. Fixing this kind of situation can take several hours because the system needs to restart and get back to its full flow capacity.

6. Base model improvement

Based on the identified bottlenecks, improvements to the simulation model were proposed. The main bottleneck significantly affecting the technical performance of the entire installation was the use of non-accumulating conveyors. As a solution to this problem, it was decided to

use accumulating conveyors equipped with drive rollers powered by an electric motor, so-called motor rollers (Figure 2). The use of this type of equipment allowed for minimizing downtime.

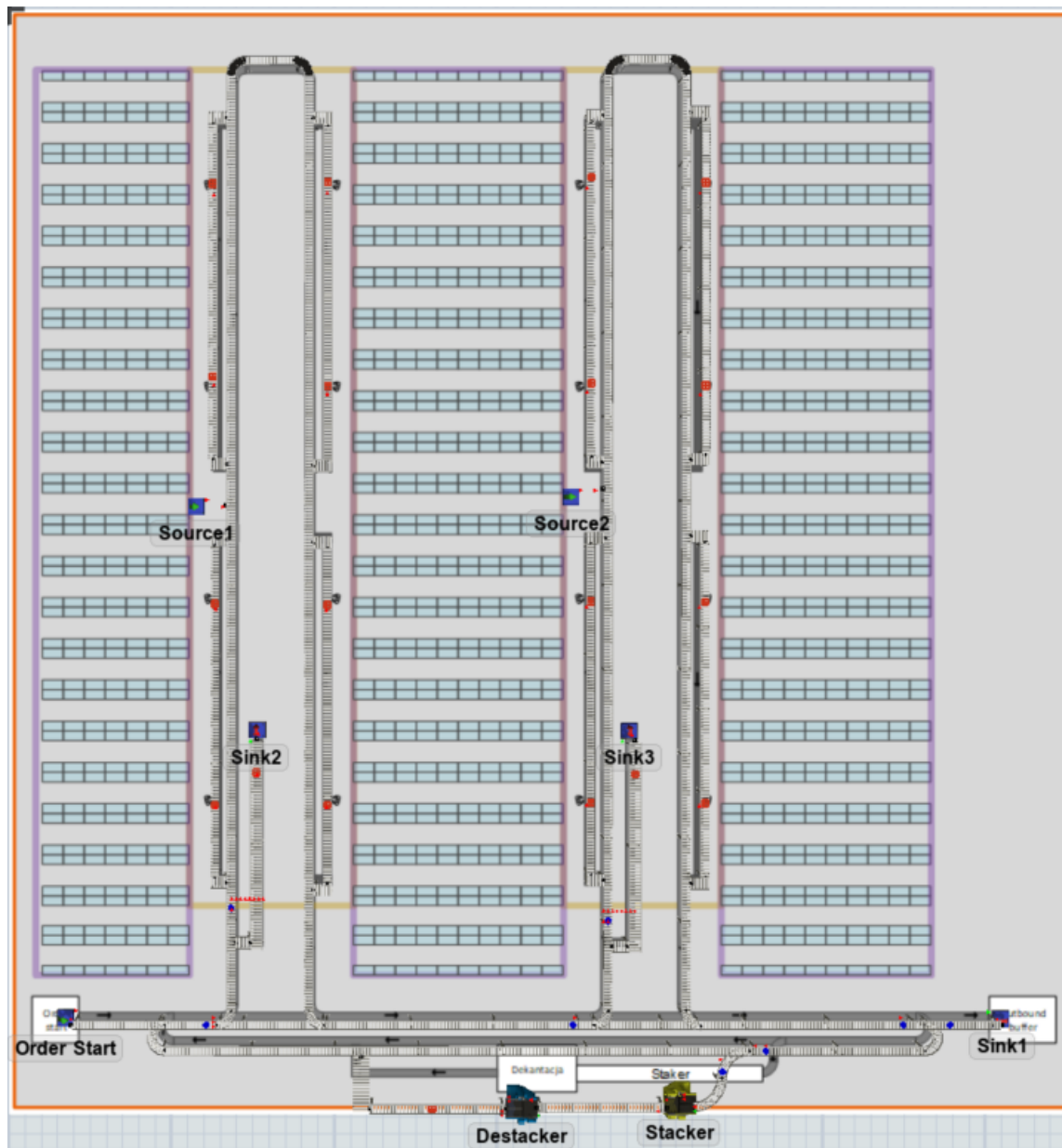


Figure 2. Improved simulation model.

Source: Own work

To increase buffer capacity, a model was developed that utilizes stacking devices. Stacking means that a container is delivered to an elevator, which raises the stack of containers. When the next container stops at a designated location, the stack is placed inside the container and lifted again. Depending on the device used, this type of solution allows for the creation of stacks of 10-20 containers high, which in the largest variant allows for an increase in buffer capacity by approximately 20 times. The overall concept for increasing buffer capacity involves the use of a stacking device at the input, which creates consolidated load units and transports them in stacks along a conveyor (Figure 3). After buffering, the containers are directed to a destacking device, which is responsible for separating the load units.

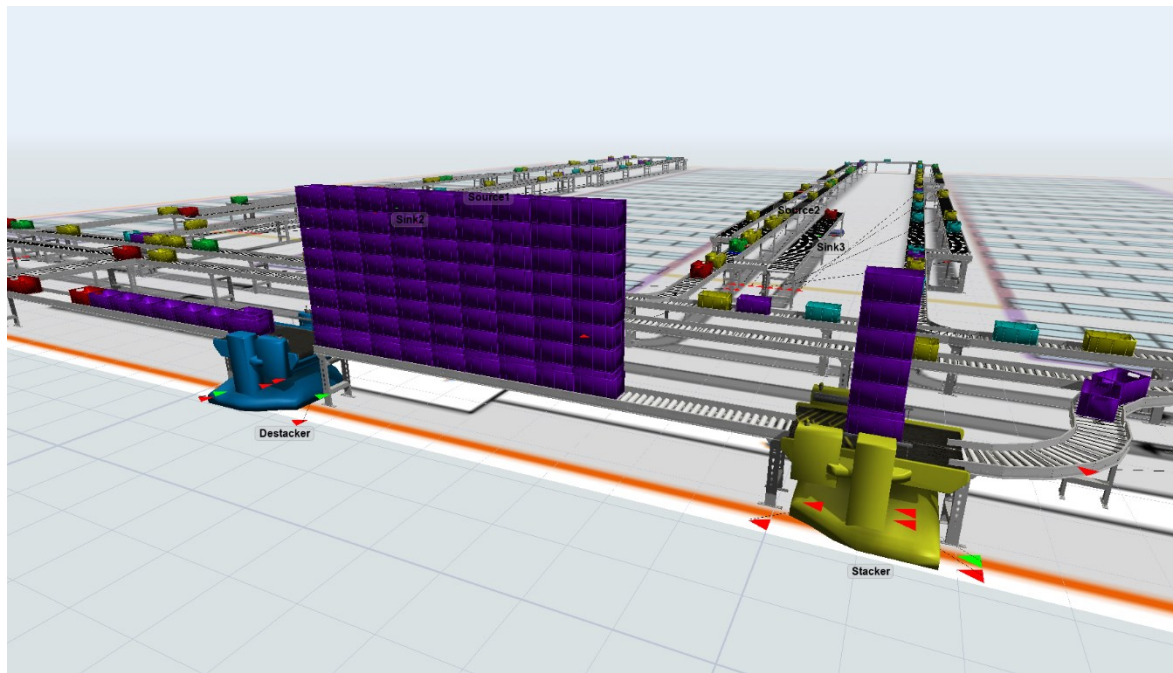


Figure 3. Stacking and destacking of the containers.

Source: Own study.

When human resources proved to be the bottleneck, the number of employees was increased to test the maximum efficiency of the installation. The study showed an increase in the efficiency of the decanting stations, as in the baseline model, the workstations had a maximum technical capacity of 480 containers per hour. Therefore, increasing the flow in the model prevented decanting from achieving the intended plan due to limited technical throughput. To increase efficiency, the station's cycle time was reduced to approximately 5 seconds. This reduction in cycle time eliminated the bottleneck. The refilling station was subjected to the same adjustment, as its cycle time depended primarily on the number of operators performing the process. To ensure continuous flow and eliminate the bottleneck resulting from the number of human resources, the cycle time was reduced from 15 seconds to 10 seconds.

7. Analysis of the capabilities of the base model and the improved model

In the experimental phase, the system's efficiency was examined for various takt times and process cycles. Two variants were examined:

- the number of containers with completed components that left the system during an hour, a shift, and a full day,
- the number of containers that were sent as replenishment to picking locations, also during an hour, a shift, and a full day.

To simplify the simulation model, it was assumed that there should always be a balance between picking and replenishment. This assumption eliminated unknown parameters and random factors that could distort the simulation results. The primary goal was to achieve repeatability, therefore, a single strategy was tested, balanced for both the baseline and improved models.

As part of the research, 72 measurements were performed, which were divided into two research phases. The first phase, in which 40 measurements were performed, was aimed at examining the base model, while 32 measurements were performed in relation to the already improved model. The smaller amount of measurement was due to the fact that the installation reached its maximum at the 32nd measurement, which was a significant improvement compared to the base model. The tests carried out showed that for non-accumulating conveyors, the maximum system efficiency at which 100% stability occurred was approximately 600 containers per hour, while with accumulating conveyors, the maximum technical efficiency was 1000 containers per hour (Figure 4).

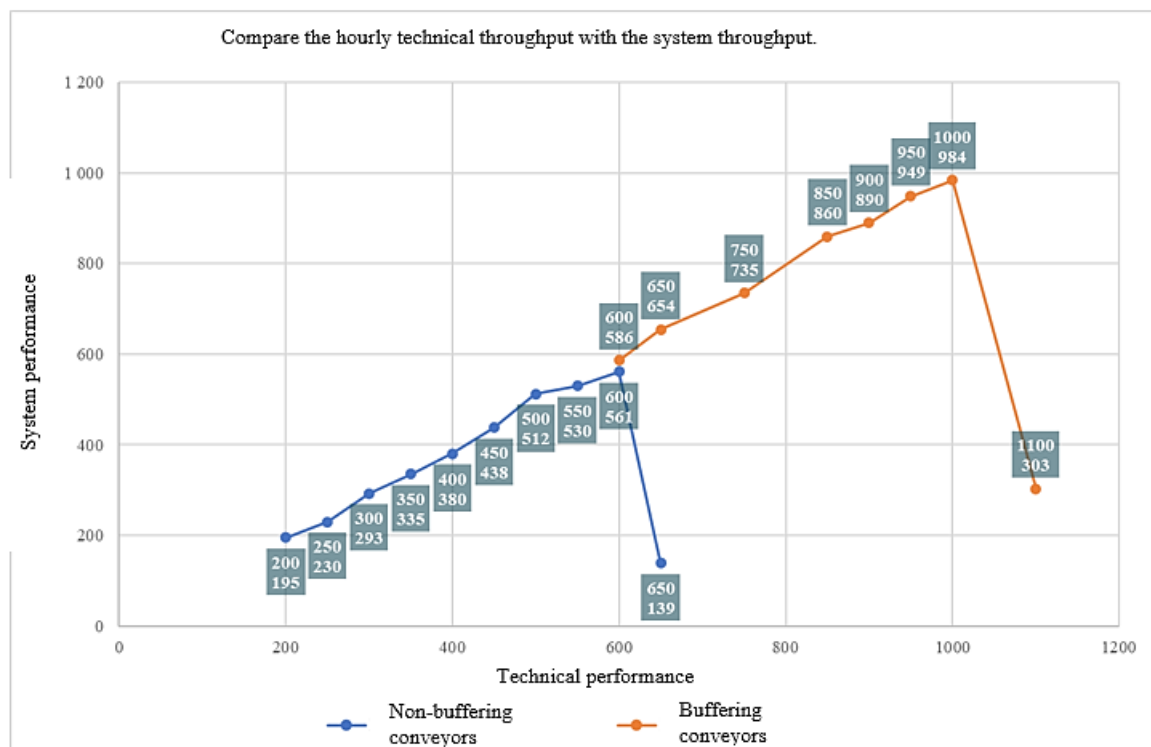


Figure 4. Comparison of system performance of research models (description in text).

Source: Own work.

8. Valuation of logistics systems

The investment required to build the baseline model is approximately €1.8 million. The costs listed in Table 1 include, among others, accumulating and non-accumulating conveyors, which are a crucial element of the logistics installation, as well as the IT system responsible for controlling the logistics process and directing the flow of containers on the conveyor. Auxiliary equipment, such as bends or transfers, which are used to redirect the flow of containers in the appropriate direction, was also estimated.

Table 1.

Valuation of the investment in the implementation of the base model

	Equipment type	Unit price	Quantity	Unit	Net price
1	Conveyors				1668675 €
1.1	Accumulation conveyor	2 500 €	385	Running meter	962 675 €
1.2	Non-accumulating conveyor	1 500 €	228	Running meter	342 000 €
1.3	Conveyor transfer	6 500 €	40	Piece	260 000 €
1.4	Conveyor bend	6 500 €	8	Piece	52 000 €
1.4	Conveyor bend	6 500 €	8	Piece	52 000 €
2	IT Warehouse Control System	120 000 €	1	System	120 000 €
Total installation cost					1 788 675 €

Source: Own study based on market analysis.

The improved simulation model incorporates accumulator conveyors into the system valuation instead of non-accumulator ones. Implementing the assumed improvements requires an investment of approximately €1.8 million for the conveyors alone, which is approximately €102,000 more than the baseline model. Other costs are presented in Table 2.

Table 2.

Investment valuation in the improved model

	Equipment type	Unit price	Quantity	Unit	Net price
1	Conveyors				1 771 000 €
1.1	Accumulation conveyor	2 500 €	568	Running meter	1 420 000 €
1.2	Conveyor transfer	6 500 €	40	Piece	260 000 €
1.3	Conveyor bend	6 500 €	14	Piece	91 000 €
2	Stacker and destacker				100 000 €
2.1	Stacker	50 000 €	1	Piece	50 000 €
2.2	Destacker	50 000 €	1	Piece	50 000 €
3	Dekantacja				65 000 €
3.1	Decanting station	5 800 €	10	Piece	58 000 €
3.2	Code scanner	700 €	10	Piece	7 000 €
4	IT Warehouse Control System	300 000 €	1	System	300 000 €
Total installation cost					2 236 000 €

Source: Own study based on market analysis.

In terms of CAPEX (Capital Expenditure), the improved model requires approximately €514,000 more investment. The percentage difference between the baseline and improved models is approximately 25%. The comparison takes into account, among other things, the "unexpected investments and costs" parameter, which in this type of project fluctuates

around 15%. An investment buffer has been added to the base amount to secure funds for design changes and to cover the potential costs of additional certificates or building permits.

9. Conclusions

As a result of the design work, a so-called baseline model of the transport conveyor network system was developed, which was to be purchased and implemented in the warehouse. The presented research demonstrated that using simulation tools, it was possible to create an improved baseline model and then compare these models in terms of performance and purchase costs. The research demonstrated that the improved logistics model is characterized by significantly higher technical efficiency, almost twice as high as the baseline model. In this study, the improvements yielded a positive result, improving the number of order containers fulfilled by approximately 67% and increasing the number of replenishments by nearly 75% compared to the baseline model. It should be noted that the improved transport conveyor network model did not significantly increase the warehouse space occupied.

The information obtained from the computer simulation is helpful in making decisions about the selection of a transport system, as it allows for weighing the benefits against the costs of the selected model. The research shows that the best solution is to implement an improved model, however, due to the additional investment outlays, which amount to approximately EUR 515,000 thousand, the company may decide to use the basic model and, as business needs increase, rebuild the installation.

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