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THE IMPLEMENTATION OF A TIER-CAPTIVE SBS/RS SOLUTION: A CASE STUDY

Beata NOWOTARSKA-ROMANIAK[1*], Sonia SZCZEPANIK[2], Aleksandra BANAŚ[3]

[1] Katowice University of Economics; beata.nowotarska-romaniak@uekat.pl, ORCID: 0000-0003-3563-2596
[2] Katowice University of Economics; sonia.szczepanik@edu.uekat.pl, ORCID: 0000-0002-4275-3700
[3] Katowice University of Economics; aleksandra.banas1@edu.uekat.pl
* Correspondence author

Purpose: The goal of this research is to provide a practical demonstration of the tier-captive SBS/RS system's step-by-step implementation procedure. This includes making the necessary modifications to the warehouse's operating system, a comparison of investment efficiency, and an examination of the specific advantages and disadvantages of the implemented system.
Design/methodology/approach: The article follows case study method, focusing on one deliberate chosen enterprise, utilizing mixed methods research: two in-depth interviews with warehouse managers, WMS (Warehouse Management System) and Kisoft data analysis.
Findings: The distribution company found that tier-captive SBS/RS system solutions in warehouses can improve efficiency, reduce employee numbers, and increase speed. The automated warehoused equipped with tier-captive SBS/RS system achieved higher picking efficiency and a shorter picking time. However, implementing these solutions requires overcoming financial barriers, proper training, and addressing human errors. Despite these challenges, the company continues to update IT systems, inspect parts, and replace parts. Despite these benefits, personnel will never be completely replaced by these systems, as they will still be responsible for controlling processes, making changes, and making changes where errors occur.
Research limitations: Case studies by definition may lead to an external validity; the chosen sample may hardly allow for necessary generalization; triangulation methods allow for mistakes such as biased information, cause errors due to inappropriate question construction, inaccuracies, or attempts to present the company from a better perspective or maintain anonymity.
Originality/value: The use of case study method provides unique perspective into the well-researched field of literature and detailed insight into a highly secure field of innovation deployment into the warehouse system.
Keywords: warehousing, AS/RS, SBS/RS, tier-captive.
Category of the paper: Case study.

1. Introduction

In today's business landscape, logistical customer service plays a crucial role in gaining and retaining customers. The key to successful logistic customer service lies in the efficient and effective management of material and information flows, which directly impacts customer satisfaction during the purchasing process (Kauf, 2016, p. 58). Companies strive to establish a competitive edge by investing in the newest 4.0 warehousing logistics solutions and by offering exceptional customer service that enhances market position and provides the opportunity to gain a time and space advantage.

Manufacturing and service organisations devote a substantial portion of their resources, including time and money, to the process of designing or redesigning their facilities. This process entails assessing how the tangible resources of the organisation may most effectively contribute to achieving the company's objectives. Third-party logistics companies are critical in the warehousing industry due to the growing practice of outsourcing logistical activities. Many organisations choose to delegate their warehouse operations to third-party logistics providers to improve the efficiency of their supply chain. Recent developments in 4.0 logistics have led to the incorporation of automated technologies in organisations.

For several reasons, warehouses play a vital role for manufacturing enterprises operating within the supply chain. First, they facilitate coordination between production and customer demand by storing products for a specific period. Secondly, they gather and consolidate products from different producers for combined shipments. Thirdly, they facilitate same-day delivery for both production and important customers. Lastly, they support activities such as product customisation, packaging, and final assembly (Lerher, 2018).

Investing in new or upgraded material handling technology, such as any sort of automated storage and retrieval system in a warehouse, offers a significant chance to enhance corporate performance. Tier-captive SBS/RS systems are one of the most recent innovations that have transformed warehouse operations by providing efficient and automated solutions for storage and retrieval activities. The process involves employing self-driving shuttle robots or vehicles to transport and store goods within a warehouse. These shuttles operate autonomously within the racks or shelves, monitoring inventory and easing product movement.

However, the broad literature available does not provide much information concerning the process of introducing such a crucial investment into the company. This study aims to provide a step-by-step demonstration of the implementation process of a tier-captive SBS/RS system, including adjustments to warehouse working systems, investment efficiency comparisons, and an analysis of the system's advantages and disadvantages. To achieve its objective, the study employs the case study method that involves mixed-methods research: two in-depth interviews with warehouse managers, WMS (Warehouse Management System), and Kisoft data analysis.

2. Literature review

The automated storage and retrieval system (AS/RS) is a key material handling technology that is commonly used in distribution centers. Traditionally, AS/RSs have been classified as fixed-area equipment that can serve goods within a 3D area or a cube, similarly to jib cranes or bridge cranes (Meyers, Stephens, 2013, p. 251). AS/RS has been a vital tool for warehouse storage and inventory control since its development in the 1950s (Vasili, Tang, Vasil, 2014, p. 162). The main advantages of AS/RSs are savings in labour costs and floor space, increased reliability, and reduced error rates (Lerher et al., 2015b, p. 48). In the broadest sense, AS/RSs can be defined as a combination of equipment and controls that automatically handle, store, and retrieve materials with outstanding speed and accuracy without direct handling by a human worker (Linn, Wysk, 1990; Manzini, Gamberi, Regattieri, 2006; Lee Souza, Ong, 1996). This definition covers a wide variety of systems with varying degrees of complexity and size. The standard AS/RS system consists of a few subsystems, such as: single one- or multiple parallel aisles with multi-tiered racks; stacker cranes (also referred to as storage/retrieval machines or S/R machines); input/output (I/O) stations (pickup/delivery stations, P/D stations, or docks); accumulating conveyors, and a central supervisory computer and communication system (Lee Souza, Ong, 1996; Van den Berg, Gademann, 2000).

As the material handling sector evolves rapidly, suppliers create innovative solutions to accommodate the trend of smaller order amounts, a diverse product range, and quicker deliveries. In order to meet the demand for higher productivity and comply with time constraints for deliveries in the warehouse, managers opt for a tall storage area with a small footprint to maximise space utilisation in the warehouse (Lerher et al., 2015b, p. 48). Having several levels in a storage area requires a fast and effective storage and retrieval system to handle loads quickly and boost throughput capacity (Lerher et al., 2016, p. 715).

Literature provides various classifications of concepts for AS/RSs; the following one allows for identifications of type of stacker crane, way of material handling, and different rack solutions (Figure 1). Stacker crane technology is based on a rectangular-geometry robot or vehicle operating to store and retrieve loads into and from the storage cells. This autonomous vehicle has a vertical drive, a horizontal drive, and usually one or two shuttle drives (Vasil, Tang, Vasil, 2014, p. 166).

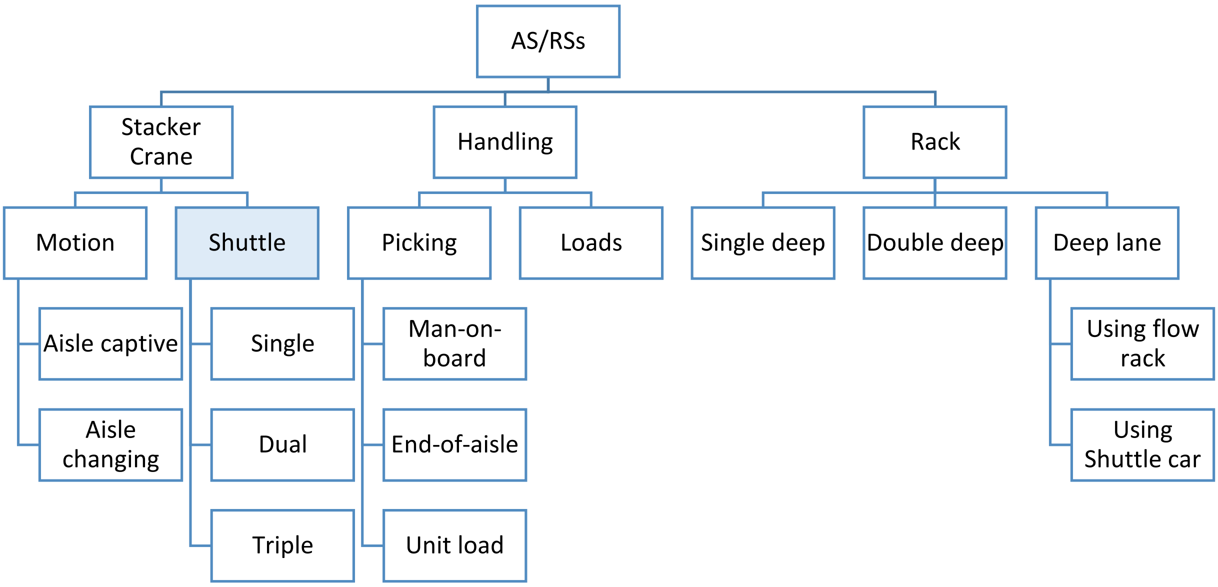

Figure 1. Various system concepts for AS/RSs.

Source: Vasili, Tang, Vasil, 2012, p. 165.

AS/RS technology is evolving in response to current market trends. The current trend leans towards greater product variety with fewer quantities in terms of orders and production batches and a rapid transaction process (Ha, Chae, 2018; Ekren et al., 2018; Bahurdin, Othman, Tuan Dir, 2020). As of today, there are two primary AS/RS configurations available: one utilises tier-captive shuttles, while the other employs tier-to-tier shuttles. The tier-to-tier configuration of AS/RS systems is typically employed for handling significant pallet unit loads, while the tier-captive design is more commonly used for the movement of small products, such as totes and trays (Ekren et al., 2018, p. 110).

The literature refers to the entire system as a shuttle-based AS/RS system (SBS/RS) because it functions using shuttle configuration mechanisms. Malmborg (1996) introduced the term SBS/RS to the system previously known as autonomous vehicle storage and retrieval systems (Fukunari, Malmborg, 2008; Kuo, Krishnamurthy, Malmborg, 2007; Ekren, Heragu, 2012).

Tier-captive SBS/RS is also known in the literature as the mini-load storage system, which is thought to be light-weight and energy efficient compared to others (Ekren et al., 2018, p. 110). Many industries have made tier-captive SBS/RSs that work well and have fast cycle times and high throughput capacities, but their rigid designs make it hard for them to adapt to the frequent changes in warehouse management (Ha, Chae, 2018, p. 13). This system is offered by multi-aisle captive systems by various companies, such as Dematic, OS-RS by Knapp, SQS by SSI Schafer, and Quickstore HDS by Vanderlande Industries (Ekren, Akpunar, Sari, Lerher, 2018, p. 110).

The components and operating features of the tier-captive SBS/RS are nearly identical to those of the conventional AS/RS, including the storage structure, storage and retrieval machine (SRM), storage module, input and output stations, and control system (Bahurdin, Othman, Tuan Dir, 2020, p. 4431).

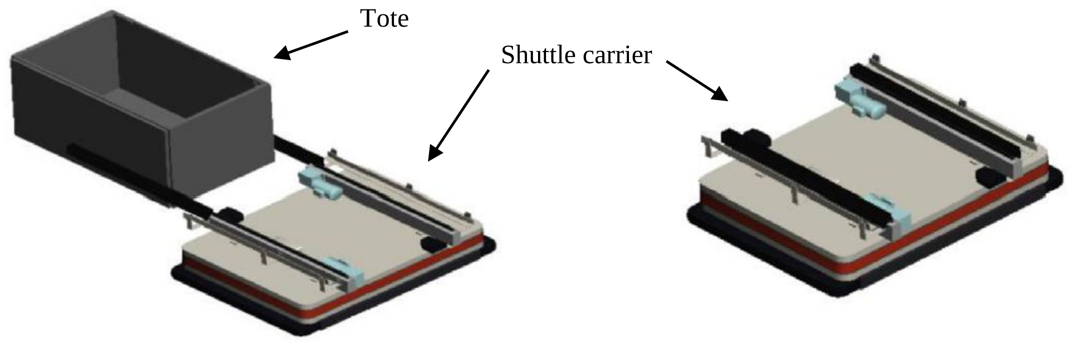

Figure 2. Storage module (tote) and shuttle carrier.

Source: Ha, Chae, 2018, p. 13; Bahurdin, Othman, Tuan Dir, 2020, p. 4431.

Rack formations, including individual storage compartments like totes or trays and shuttles, comprise storage modules (Figure 2). A storage module is a configuration of racks that includes separate storage compartments, such as totes or trays, and shuttles (Figure 3). The shuttles, which act as transporters, travel horizontally within an aisle located between two rows of storage racks (Epp, Wiedemann, Furmans, 2017; Meng, Liu, 2015).

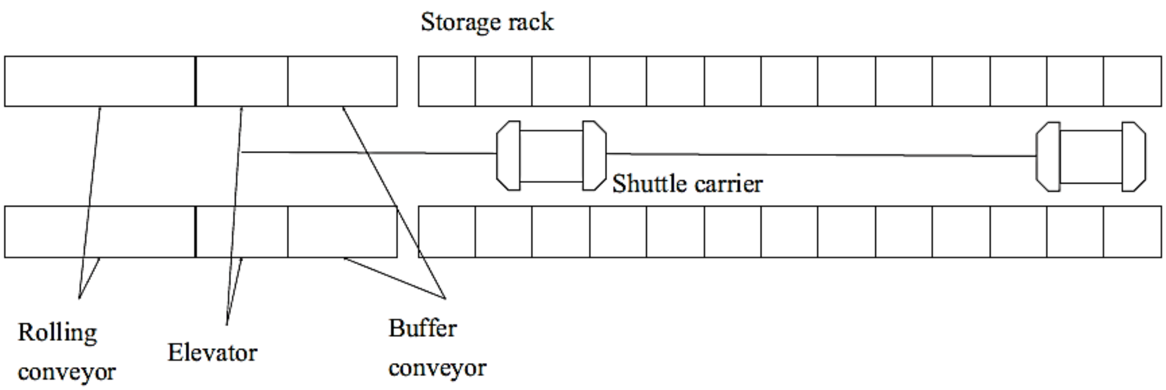

Figure 3. SBS/RS top view.

Source: Ha, Chae, 2018, p.13

A lifting device equips each cross-aisle, facilitating the vertical transportation of loads (Figure 4). The lifts transport storage transactions from the input/output (I/O) sites situated on the bottom level of each aisle to their designated tiers. Elevators also transport the retrieval transactions from their current levels to the I/O locations at their designated aisle addresses. The lifting mechanism connects the buffer areas on both sides of each tier, where shuttles transport the transactions to and from (Erken, Arslan, 2024, p. 275).

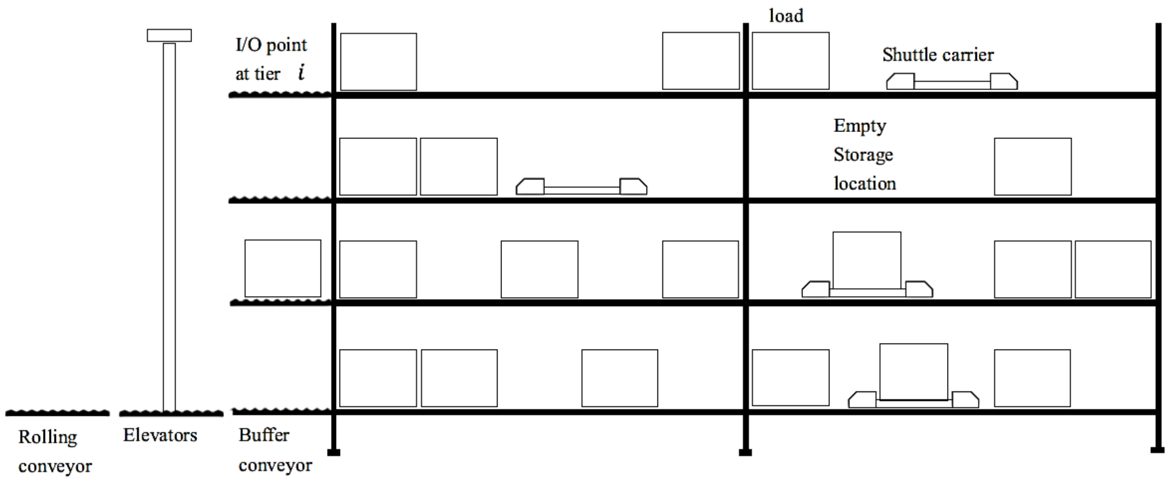

Figure 4. SBS/RS side view.

Source: Ha, Chae, 2018, p. 13.

Prior research on tier-captive SBS/RS has specifically examined the crucial elements of design flaws and the effectiveness of various system setups. One of the first and most crucial aspects of research was the take-on time and its influence on the queuing time. Marchet et al. (2011) used an open queuing network modelling technique to simulate the construction of tier-captive SBS/RS and to accurately determine the typical waiting time and mean cycle time for transaction performance indicators. In their subsequent publications, Marchet et al. (2013) successfully demonstrated the design trade-offs of tier-captive SBS and RS through the use of simulation modelling. Their findings indicated that reducing the number of aisles leads to a decrease in the system's investment expenses. The works of Carlo and Vis (2012) investigated a novel variant of a tier-captive SBS/RS system used by a company in the Netherlands, equipped with non-passing lifting mechanisms. Researchers consequently developed heuristic-based scheduling algorithms based on the two scheduling functions of these elevators.

In their study, Lerher et al. (2015b) demonstrated the benefits of the tier-captive SBS/RS by conducting a comparison with an alternative warehousing system. They specifically highlighted the rate performance measures for various warehouse designs. In a separate study, Lerher (2015) investigated double-deep storage compartments in a tier-captive SBS/RS. This racking system has the benefit of reducing floor space utilisation by reducing the number of lanes in the system. Lerher et al. (2015a, 2016) created analytical models to calculate trip time in a tier-captive SBS/RS. These models take into account the velocity profiles of shuttles and lifts, such as acceleration, deceleration, and maximum velocities. Additionally, the models consider the scheduling rules for transactions in the systems, including both single and dual command scheduling. Ekren, Sari, and Lerher (2015) conducted a study on the effectiveness of a class-based storage strategy in a tier-captive SBS/RS using simulation modelling. The study compared the efficiency of the class-based storage policy with a random storage policy.

In their study, Ekren and Heragu (2011) introduced simulation-based design methods for a distinct iteration of automated warehousing technology. Ekren (2017) demonstrated the design trade-offs of a tier-captive SBS/RS in various warehouse designs. The study featured many graphs that depicted performance indicators for each design. These findings enable warehouse managers to select the most suitable design depending on their specific requirements. Ekren et al. (2018) introduced analytical models that forecast the average and variability of the trip time for lifts and shuttles in a tier-captive SBS/RS. These models can also forecast the average energy consumption and energy regeneration per transaction by considering various design characteristics such as the velocity profiles of vehicles and lifts, the number of levels, the number of bays, and so on.

In their 2015 study, Wang, Mou, and Wu introduced a mathematical methodology to efficiently schedule work in a tier-captive SBS/RS. The researchers use a non-dominated sorting genetic algorithm (GA) to determine a solution that is best for many objectives. Tappia et al. (2016) introduced a queuing network model that forecasts several performance indicators based on a tier-captive SBS/RS. Zou et al. (2016) created an approximation model using a fork-join queueing network technique to figure out different performance indicators for an SBS/RS that is captive at the tier level. The model accounted for the sequential movement and simultaneous processing of cars and lifts. Eder (2019) researched an open queueing network (OQN) that works continuously but has limited capacity to determine important performance metrics for a tier-captive SBS/RS architecture.

Kazemi, Asef-Vaziri, and Shojaei (2019) introduced an innovative hybrid approach that integrates the ant colony algorithm with adaptive large neighbourhood search. Their system design incorporates a storage and retrieval mechanism capable of simultaneous movement in both horizontal and vertical orientations. The system relies on shuttles to navigate through the aisles. Liu et al. (2021) conducted a recent study on a tier-captive SBS/RS, in which they developed a mathematical model that incorporates a cross-aisle shuttle responsible for transporting transactions across aisles. They assessed the processing speeds, movement times, and energy consumption. Furthermore, the most favourable velocity and acceleration parameters undergo analysis. Wauters et al. (2016) investigated the design of a mini-load AS/RS system that integrates a twin shuttle crane. They implemented a mathematical model and several heuristic algorithms to optimise the system.

Ekren (2020a) has recently conducted research on tier-captive SBS and RS. In her research, she examines a statistical experimental design to determine the key design parameters that impact the performance of tier-captive SBS and RS. The study demonstrated a clear correlation between the number of aisles in the system and its performance, with a notable impact. Ekren (2021) proposed a multi-objective optimization approach for designing a tier-captive SBS/RS. The study considers the reduction of both the average cycle time per transaction and the energy consumption per transaction as multi-objectives. Ekren and Akpunar (2021) introduced a tool capable of calculating many performance indicators based on a pre-established

SBS/RS architecture. They created the tool using an open queuing network modelling technique and made it available for free through a website.

This paper provides a thorough overview of the efficient operation of a tier-captive SBS/RS system. The majority of the recalled authors employ an analytical or modelling approach. This has been a typical technique in the field of AS/RS since its beginnings (Casella et al., 2023). Based on the literature review, there is a limited number of researchers who primarily focus on tier-captive SBS/RS systems that rely on data obtained from business companies. Instead, they predominantly base their results on data models. Incorporating SBS/RS into an existing warehouse is a substantial task for any company, so it is essential to additionally include qualitative data. Little attention has been drawn to the management aspects of introducing tier-captive SBS and RS systems into an already existing warehousing environment.

3. Research methodology

This study aims to demonstrate the step-by-step process of implementing the tier-captive SBS/RS system, including necessary modifications to the warehouse working system, an evaluation of the investment efficiency, and an analysis of the specific advantages and disadvantages of the implemented adjustments. Due to the low level of understanding of the managerial aspects of the issue discussed, the most suitable approach for this study is the utilisation of the case study method.

Given the broad scope of the literature in analytical and modelling approaches, the researchers decided to conduct a single descriptive case study in Yin's (2003a, 2003b) theory. The need to comprehensively describe the phenomenon in question, considering its context of occurrence, justifies this choice. The decision to select a single case study is also justified by Yin's theory (2003a, pp. 40-42) because it describes phenomena that have so far been beyond the scope of researchers' interests.

Researchers used the following criteria to guide their search for a suitable company to conduct the study: The organisation conducts business in Poland and additionally stores, packages, and ships products within the country. The company implemented the tier-captive SBS/RS systems more than five years ago. In January 2024, the search for an organization that met the criteria began. The company that fulfilled all the criteria and opted to participate in the research requested anonymity. It substantiated this request by providing confidential data that would facilitate its identification. The researchers agreed to this proposal and, at the same time, obtained all the necessary materials to conduct the study.

The study conducted two in-depth interviews with warehouse managers in February and March 2024. The interviews aimed to collect data on the following topics: the existing warehouse solutions and the implementation of the tier-captive SBS/RS system; the main management concerns prior to the introduction of the new system; the major advantages and disadvantages of implementing the new system; and the planned future investments.

The study incorporated data from the Warehouse Management System (WMS) regarding the manual warehouse's picking process as well as the Kisoft system report regarding the automated warehouse. The acquired data focused on February 2024 and included daily and monthly reports from 2022 and 2023 comparing various metrics, such as the number of completed lines in the manual and automated warehouse sections. Performed data analysis allowed to determine:

- picking efficiency by manual and by tier-captive SBS/RS system (in total and by shift),
- average picking time of 1 line (order item) by manual and by tier-captive SBS/RS system,
- share of the number of lines implemented by tier-captive SBS/RS system in relation to the total number of lines in 2022-2023,
- average number of lines completed by tier-captive SBS/RS system and by manual in 2022-2023.

4. Results

4.1. Characteristics of the assessed company

The multinational corporation under investigation operates in dozens of European countries. It has been in business in Poland for over 25 years, selling and distributing several dozen multinational brands of food, chemicals, cosmetics, clothes, and footwear, as well as toys and small electrical gadgets. The company sells things both online and through Allegro. For its stationery stores, it is the sole Polish distributor. In Poland, the company distributes products to both large retail chains and small businesses, as well as individual customers. The company also provides logistical services such as warehousing, co-packing, transportation, and reverse logistics. It has two warehouses: one near Warsaw and the other near Poznań. This paper presents a case study of a warehouse located in Warsaw that only utilises tier-captive SBS/RS technologies.

4.2. The process of implementation of a tier-captive SBS/RS system

During its initial phase of operation in Poland, the company consisted of multiple enterprises involved in the trade of products from various industries, leading to the establishment of three separate warehouses. In 2021, the company decided to consolidate its businesses and establish a unified warehouse near Warsaw. These activities necessitated the modification of the entire infrastructure to accommodate all the firms' activities in a single area. The company-initiated conversations regarding the installation of automated technologies in its warehouse in 2019. The company began to collect information on turnover, product delivery, types, and picking techniques. The proliferation of competitive businesses in the area, coupled with the onset of the COVID-19 epidemic, accelerated this progression due to the company's encounter with a scarcity of labor. After evaluating the use of automation for 1.5 years, the company ultimately decided to introduce the Knapp OSR Shuttle EVO system (Figure 5). In addition to the Knapp OSR Shuttle EVO system, the company also acquired automated labelling equipment in March 2024 to enhance the efficiency of applying labels to items as part of the co-packing service.

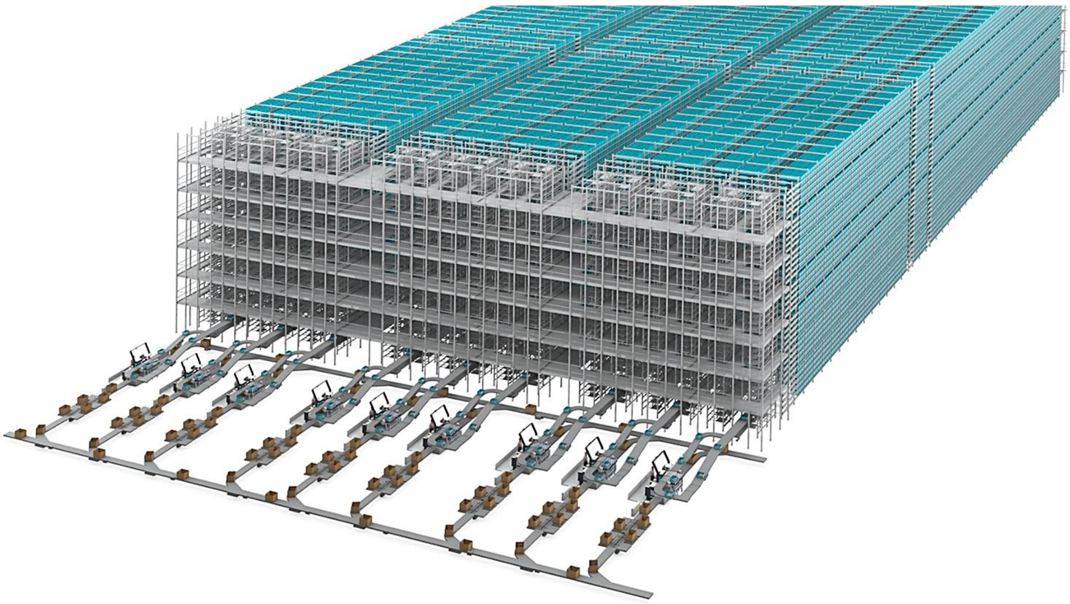

Figure 5. OSR Shuttle Evo.

Source: Knapp - OSR Shuttle Evo.

The automated OSR Shuttle System stores goods in totes on racks. It transports these containers using shuttles and elevators, moving them from refilling locations to designated rack locations, then to picking stations for inspection and loading onto a pallet. The company tailored the OSR Shuttle Evo, a tier-captive SBS/RS system, to its business needs. The manufacturer offers various sizes of automated shelves (250 x 250 mm to 850 x 650 mm). The company decided to choose shelves for 46,000 containers with dimensions of 400 mm high and 600 mm by 380 mm. The manufacturer's design provides for the possibility of dividing the totes into 2, 4, 6, or 8 parts to accommodate the types of products supported. The system's sprinklers, which neutralise chemical hazards, supported the choice of OSR Shuttle EVO for storing chemical goods.

At a new site, the company had to establish a WMS (Warehouse Management System), modified from previous warehouses, to handle all products in one area. It was also important to adopt an automation supplier's system to administer the newly introduced automated solution, the Kisoft system. This system manages the movement of relevant totes to the picking stations and oversees the picking process, which includes displaying messages on the screen for personnel about the type and quantity of products selected for a specific order. It manages the entire automated system by utilizing the data it collects. It collaborates with the WMS system to generate documentation, as well as integrates with ERP (enterprise resource planning) systems to access pertinent data. The Warehouse Management System (WMS) keeps a comprehensive record of all items that are currently available in stock.

If there are orders that will eventually be placed in a designated box or envelope, the items can be promptly packaged into boxes or containers. The cardboard boxes undergo mechanical folding and are imprinted with barcodes that include the SSCC number. Containers already have these barcodes, which are only read and registered once for a single order. Containers and boxes travel along rollers equipped with laser barcode readers for product identification. When the box approaches the first appropriate picking station, the sensor detects this, and the rollers adjust their position to bring the box to the correct location. The Kisoft system begins the process of delivering appropriate containers with products from the shelves to the appropriate picking stations; the shuttle picks up the appropriate container from the shelf and transports it to the belt using an elevator, and the container with the product, like the box into which orders will be picked, is delivered to the appropriate picking station. Two tiers of rollers make up the system for carrying containers: lower rollers insert products from the order into boxes, while upper rollers transport containers for picking.

At each picking station (Figure 5), there is a screen that displays information on which container or part of it the employee should take the product from, how much to take, and where to store it. Upon completing each assignment, the employee must confirm it by clicking a button; subsequently, the product-taking container moves forward and a new one takes its place.

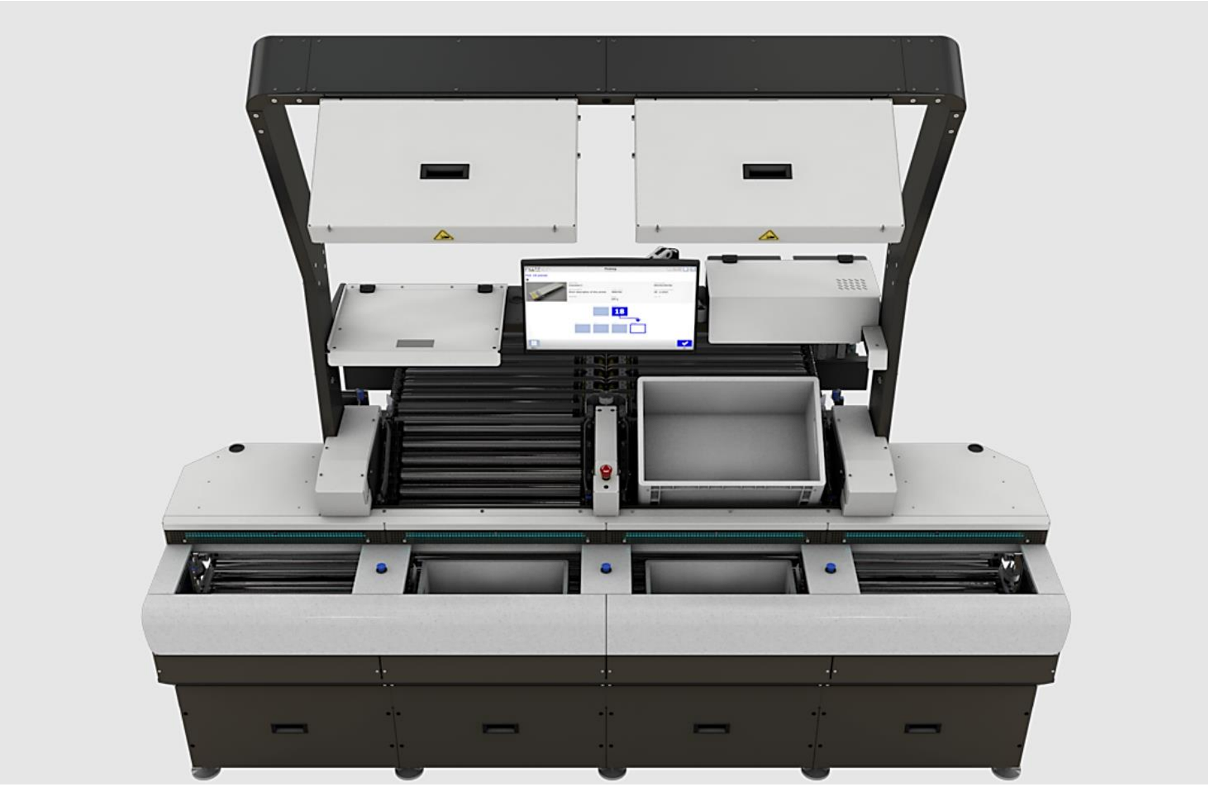

Figure 5. Picking station OSR Shuttle Evo.

Source: Knapp - OSR Shuttle Evo Picking station.

Once the entire order is completed, it is placed in the container on the primary roller and transported to the weighing station for verification of the order's weight. If an employee fails to comply, they transfer the container or box to the error station, where they examine and correct the improper completion. The document printing station receives an accurately completed order. The station prints all the necessary documents requested by the customer, including the stock issue confirmation (CI) and invoice. The station then packs these documents in a container or box. The entire process operates automatically, eliminating the need for human intervention.

Next, an employee transfers the order within the box to the filling station and fills it with the appropriate filler material, such as paper. Next, the employee moves the box to the station and uses compressed air and hot glue to automatically seal it with a cardboard cap. The station then sends the reweighed order to either a shipping label printing station for boxes or a repacking station for containers. The repacking station places the order in a specifically designated box or envelope. The designated pallet receives orders that are ready for shipment.

The warehouse that utilises the OSR Shuttle Evo operates on a three-shift schedule. The first shift runs from 6 a.m. to 2 p.m., the second shift runs from 2 p.m. to 10 p.m., and the third shift runs from 10 p.m. to 6 a.m. During each shift, there is a designated leader who is responsible for overseeing the automatic component, as well as sub-leaders who are responsible for allocating work in different regions of the warehouse. The tasks assigned to individual personnel can be categorised as follows:

– replenishing products to the OSR Shuttle Evo,
– registering boxes and the contents of the goods,
– picking at picking stations,
– operating the error station,
– handling the filling and securing of goods and boxes.

Furthermore, the company utilizes Power BI, a technology that facilitates the study of Big Data, as part of Logistics 4.0, alongside automation. IT analysts create a range of reports that are thereafter accessible to approved users. Pallet filling is a specific type of report that is commonly found in warehouses. Upon implementing automation and its corresponding IT system, the corporation had the choice to acquire a performance module that would generate information on employee task productivity within the automated portion. The determination of this matter is now pending, however there are plans to make such an investment in the future.

At present, the company is contemplating implementing AGV (Automated Guided Vehicle) or AMR (Autonomous Mobile Robot) trolleys. These trolleys would be tasked with transporting goods from the receiving area to the designated location within the warehouse. An operator would then place the goods on the shelf. Additionally, the trolleys would also handle the reverse process of transporting goods from the shelf to the picking area or directly to the loading site. The firm is contemplating the option of leasing and evaluating these trolleys for either a short or long duration, as this solution entails a considerable expense. In addition, the scarcity of organisations offering these products makes it challenging to calculate the ROI (Return on Investment Index), which is crucial for making investment decisions. The corporation is now exploring the potential of using automated loading and unloading docks. This method decreases the duration of loading and unloading from 60 minutes to 15 minutes.

4.3. A comparison of the OSR Shuttle Evo and manual warehouse efficiency solutions

4.3.1. Picking efficiency in February 2024

To compare the efficiency of work in the warehouse for automated and manual portions, the average picking efficiency was computed in February 2024 using the company's WMS and Kisoft data. The report on the automated warehouse included information such as the time spent putting and collecting products in tots into the OSR Shuttle Evo, the number of tots thrown in, lines and pieces collected, and the number of people responsible for launching, collecting, and non-countable work (e.g., cleaning, measuring products).

The average efficiency of an employee on a given shift was determined by considering the number of lines finished (i.e., order items), the number of employees on the shift, and the time spent picking. The average monthly total productivity was then calculated, divided into shifts, and expressed as the number of lines finished by one person each hour. The productivity report, which was used to analyse performance in the manual warehouse, contained information on all picking operations of all employees in the examined period—from what location the employee picked the goods, in what quantity, at what time, and to what location he delivered them, as well as at what time the operation started. During the pick-up process, employees use a scanner to generate this data. When picking a specific product, the employee scans the barcode on the shelf from which they choose the items (which is akin to starting the picking process), then travels to the next position and scans the barcode again, marking the start of a new operation. We processed the data to calculate the collection efficiency and then the average picking times for a single line. We will present the results in the next part of the article: we calculated the difference between the completion times of two consecutive activities, and identified those for which the difference between the calculated time and the execution of the operation included in the report was longer than 5 seconds, indicating incorrectly recorded data.

Then, we calculated and expressed the picking efficiency of each employee in the same manner as the automated part, based on the designated times of all picking operations performed by individual employees and the number of completed lines. Finally, from the results obtained, the average monthly picking efficiency in the manual part was determined in total and divided into shifts. Table 1 shows the total average picking efficiency, divided into shifts in the automated and manual parts of the warehouse in February 2024.

Table 1.
Average picking efficiency in February 2024 (number of lines/1 person/1 hour) in the automated and manual parts of the warehouse

	Total	1st shift	2nd shift	3rd shift
Automated warehouse (OSR Shuttle Evo)	169	153	193	161
Manual warehouse	79	91	77	71

Source: own elaboration based on data provided by the company.

The analysis reveals that the 2nd shift (193 lines/1 hour/1 person) in the automated part and the 1st shift (91 lines/1 hour/1 person) in the manual warehouse had the highest picking efficiency in February 2024. However, the lowest efficiency occurred on the 1st shift (153 lines/1 hour/1 person) in the automated part and on the 3rd shift (71 lines/1 person/1 hour) in the manual part. On average, one person collects 90 more lines in the automated part in 1 hour than in the manual warehouse. The automated part's "goods to person" picking eliminates the need for the employee to move around the warehouse, thereby reducing the picking time and enhancing its efficiency.

4.3.2. Average picking time in February 2024

The average picking time for one line was also analyzed. We calculated the average picking time for one line using the same data we used to determine the collection efficiency. In the automated part, dividing the amount of time spent picking during a shift by the number of pickers during a shift and the number of lines collected was the average picking time for one line during a shift. Similar to efficiency, we calculated the total average values and divided them into shifts. In the manual section, we calculated the average time for each employee to pick one line, based on the number of lines collected and the shift duration. We calculated the total average picking time from all the data and divided it into shifts. Table 2 summarises the average picking times for manual and automated parts in February 2024.

Table 2.
Average picking times of 1 line in seconds in the manual and automated parts of the warehouse in February 2024

	Total	1st shift	2nd shift	3rd shift
Automated warehouse (OSR Shuttle Evo)	3,57	3,44	1,26	6,00
Manual warehouse	27,21	24,48	27,52	28,90

Source: own elaboration based on data provided by the company.

The analysis reveals that the fastest picking occurs during the 2nd shift in the automated section and in the manual section during the 1st shift. In turn, it takes the longest on the 3rd shift in both the automated and manual parts of the warehouse. The difference between the overall picking time of one line, i.e., without division into shifts, is 23.64 seconds.

4.3.3. Share of the number of lines completed in the automated part in relation to the entire line in 2022-2023

The company generates daily and monthly reports that include information such as the sums and average quantities of lines and pieces collected in the automated part and overall, as well as the percentage of lines completed in the automated part in relation to the entire line. Figure 6 depicts the percentage of lines concluded in the automated part compared to the total number of lines gathered at that time in particular months in 2022 and 2023.

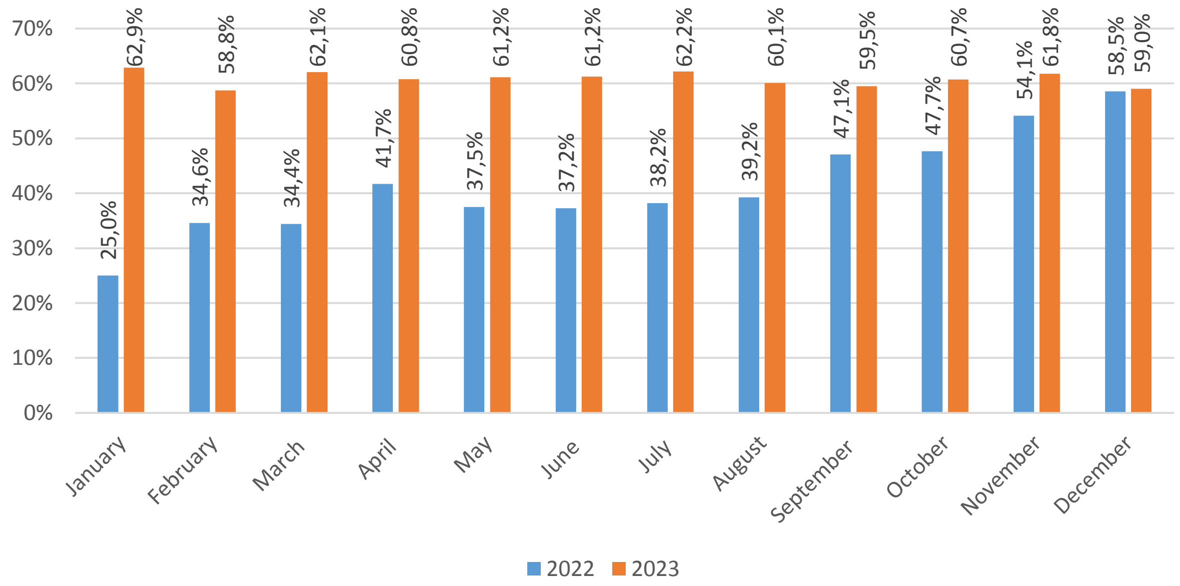

Figure 6. Percentage share of lines completed in the automated part in relation to all lines in 2022-2023. Source: own elaboration based on data provided by the company.

The presented data demonstrates that the number of lines gathered in the automated component increased the most during January and February 2022, as well as August and September 2022. From December 2022 onwards, we observed similar percentages of completed lines in the automated warehouse compared to the entire line, ranging from 58% to 63%.

4.3.4. Average number of lines completed in the automated and manual warehouse in 2022-2023

In 2023, Figure 7 illustrates the average daily collection of lines in the automated and manual sections. November saw the highest values for the automated and manual parts (12,392 lines in the automated part and 7633 lines in the manual part), while December saw the lowest values (7575 lines in the automated part and 5265 lines in the manual part). During the same months, the average number of lines completed per day in individual sections of the warehouse had the highest (4728 lines) and lowest (2311 lines) differences.

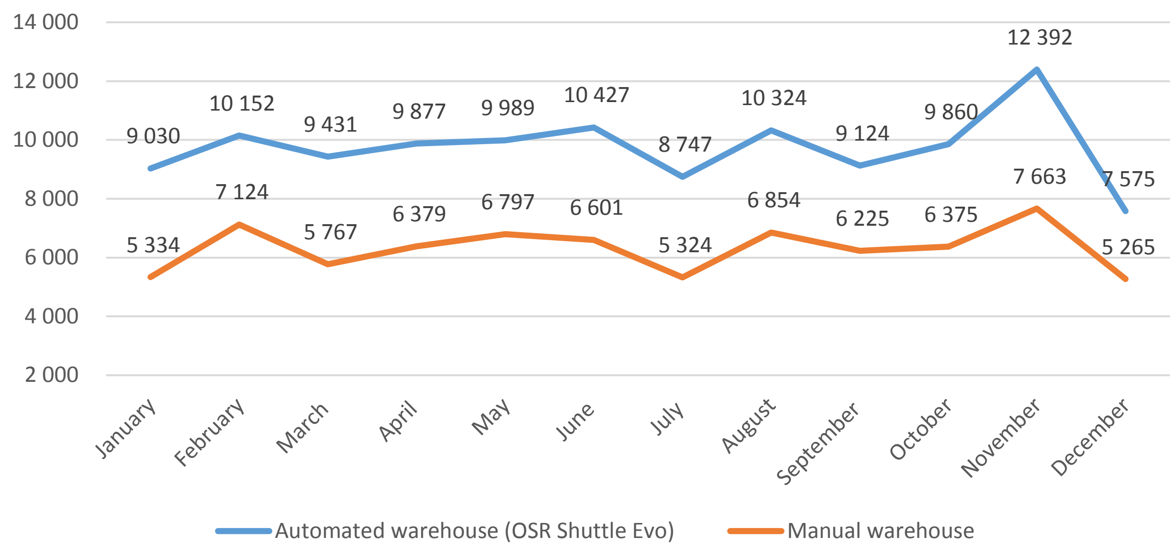

Figure 7. Average number of lines collected per day in the automated and manual parts of the warehouse in 2023.

Source: own elaboration based on data provided by the company.

4.4. Management aspects of implementing the tier-captive SBS/RS solutions

4.4.1. Barriers to the implementation of logistics tier-captive SBS/RS solutions perceived by the enterprise

During the analysis of the profitability of installing automated solutions in the warehouse, the assessed organisation identified obstacles that resulted in a prolonged decision-making process regarding their deployment. The primary obstacle was the significant upfront costs and the extended length of time required to recoup the investment—specifically, 8 years. Another obstacle was the inability to accurately forecast the extent to which productivity and pace of picking would improve and how this would correspond to the workforce size. The company anticipated a decrease in the number of warehouse personnel responsible for picking but recognised the need to hire skilled workers to operate the systems and rectify any issues that may arise in the automated component. Some of the employees who previously dealt with order picking were now responsible for restocking the OSR Shuttle EVO. Hence, it was crucial to ascertain the exact number of people possessing the specific qualifications required and how this would directly impact the expenditure on labour.

4.4.2. Benefits perceived by the company after implementing tier-captive SBS/RS solutions

The implementation of the tier-captive SBS/RS system in the warehouse has resulted in a reduction in the workforce. This ensures that the company is not concerned about a shortage of employees during periods of increased orders or unforeseen circumstances, such as the COVID-19 pandemic. Decreasing the workforce also played a role in reducing costs. Additionally, the efficiency of the selection process has improved. Furthermore, we have reduced the duration for selecting and delivering items. There is a higher likelihood of extending the "cut-off time”, which refers to the deadline for packing and shipping orders on the same day and delivering them to the client on the following business day. For orders placed through Allegro, the deadline is 12 p.m. For services offered under 3PL, the deadline is 3 p.m. The deadline for delivery to the company's stores is 5 p.m. Currently, the organisation has the capacity to efficiently fulfil a greater variety of orders within a reduced timeframe.

4.4.3. Disadvantages noticed by the company after implementing tier-captive SBS/RS solutions

Following the implementation of tier-captive SBS/RS solutions, the organisation has identified shortcomings at several levels and is actively working to eliminate them. The company's clientele exhibits diverse preferences and demands, such as varying levels of product freshness. Some customers exclusively request goods in individual units, while others solely require them in bulk packaging. Additionally, clients place orders for both individual units and products in collective packaging. Continual adaptation of the system to evolving conditions is required. The logistics process specialist, in collaboration with the IT department and the developers of the automation management system, implements changes. As an illustration, there has been a modification implemented in regard to the process of “cleaning containers”. Originally, the system operated by retrieving a product from multiple containers located in different areas. This ensured that if one of the two lifts used to transport the goods failed, there would still be a constant supply of goods available for shipping to the customer. Currently, failures are virtually non-existent due to regular inspections and part replacements. The same commodities are continuously retrieved from the adjacent container until it is empty, allowing for more frequent restocking of shelves and storage of larger amounts of products. However, customer orders with particular specifications regarding product freshness are an exception. Another modification pertained to the quantity of containers that were collected and returned. Originally, there was only one container, but now there are two containers, which enhances the efficiency of restocking shelves and picking items.

Another a disadvantage, or more accurately, obstacle, that the company encountered was the need to adjust to the system and provide suitable training for personnel. In the automated part, errors are still recorded and are divided into 3 categories:

- user errors - they are mainly based on incorrectly performed activities or disruptions in the sequence of activities,
- software errors - errors caused by problems with the operation of servers, drivers, processor and other control elements, as well as problems with the database,
- device errors – errors related to automated installation.

Additionally, within each category, based on the level of threat to occupational safety (employees, machines and devices) and the continuity of automation operation, the following are distinguished:

- high-risk errors - errors that pose a threat to work safety and/or the continuity of operation of the entire automation,
- medium risk errors – errors causing a lack of continuity in the operation of a single zone,
- low-risk errors – errors causing a lack of continuity in the operation of the device without affecting the downtime of the entire zone.

Examples of errors in each category are presented in Table 3.

Table 3.
Errors occurring in the automated part divided into categories

Error level	User errors	Software errors	Device errors
High Risk Error	– incorrectly placed carton in the carrier, resulting in an elevator stopping – leaving in a carrier, e.g., a film, which may fall out, cover the photocell, and consequently cause an emergency stop of the elevator, lock part of the conveyor, or machine – disturbance of the sequence of performance at the picking station, causing the safety procedure to be initiated	loss of shuttle or elevator positioning	– crushed or plugged out of the connector air-conditioning wire to supply the line with compressed air – the motor reducer's oil leakage – temporarily increased current consumption throughout the entire warehouse, causing the compressors to stand still.
Average Risk Error	incorrectly packed tote or carton (goods out of the outline), causing the machine or zone to be locked	– problems with barcode readers – problems caused by the loss of machine settings – overcrowding of the database	minor faults temporarily preventing the machine from working
Low-risk error	incorrectly placed carton in the totes, resulting in a problem with the deposit of the totes in the storage location	problems with downloading totes by the shuttle or putting them in storage places due to incorrect data in the database	temporary voltage jump causing mild disruption of motoreductors or motorised rollers (usually do not require intervention)

Source: own elaboration based on data provided by the company.

Table 4 shows the frequency of different types of errors in February 2024.

Table 4
Frequency of errors in the automated part in February 2024

Error Level	User Errors	Software Errors	Device Errors
High Risk Error	283	2	3
Average Risk Error	1	126	142
Low-risk error	282	142	2881
Total	**566**	**270**	**3026**

Source: own elaboration based on data provided by the company.

The largest number of errors in February 2024 concerned devices (3026 errors) and were mainly low-risk errors (2881 errors), and the least frequently observed were software errors (270 errors).

5. Discussion and conclusions

The aim of this study was to enhance comprehension of the practical execution of the sequential implementation procedure of the tier-captive SBS/RS system. This includes the necessary modifications to the warehouse operational framework, an evaluation of the investment effectiveness, and an examination of the specific pros and cons of the deployed system. The selected case study technique facilitated a thorough understanding of the introduction of the installation of OSR Shuttle Evo, a tier-captive SBS/RS, and all associated systems.

The surveyed distribution company noticed similar benefits: the efficiency of the picking process increased, the number of employees decreased, which contributed to a cost reduction, and the speed of the picking process improved, to verified in the literature. The analysis of data regarding the picking process in the automated and manual parts confirmed:

- higher picking efficiency is achieved in the automated part (expressed in the number of lines completed in 1 hour by 1 employee) - on average, 90 more lines,
- the time of picking 1 line in seconds is lower in the automated part by an average of 24 seconds.

However, the implementation of tier-captive SBS/RS system solutions in warehouses requires overcoming barriers, the largest of which are large financial outlays, which are most often mentioned in the literature and which were also mentioned by the warehouse manager during the interview. It is also necessary to properly train people to perform new functions or hire new employees with the appropriate qualifications. A few years after implementing automation, the examined distribution company notices its shortcomings, which it constantly tries to eliminate through appropriate updates of IT systems, regular inspections and replacement of parts in the automated system. Despite these efforts, errors continue to occur, including both human errors and errors related to the OSR Shuttle system and software. It is necessary to constantly adapt to changing customer requirements.

Therefore, we can conclude that the implementation of tier-captive SBS/RS system solutions in warehouses can yield numerous advantages, such as cost reduction through employee reduction and accelerated warehouse operations, albeit with certain limitations. However, it is worth remembering that people will never be completely replaced by tier-captive SBS/RS system solutions because they will be responsible, among others, for controlling processes and making changes where errors occur, but their work becomes safer and less physically demanding.

There are at least three potential limitations in this study's results. The first limitation concerns the chosen case study method. Case studies are from definition may lack external validity since they include the in-depth analysis of a particular instance of an event, in this case an implementation tier-captive SBS/RS system. Considering the current absence of important information in recent literature regarding this technique, conducting a case study is the only way to provide access to carry out research and collect the necessary data to fill the research gap.

The second limitation, perhaps the most undeniable one is generalisation, resulting from the study of a small number of cases. The forced anonymity of the examined enterprise also doesn’t allow for further market and industry comparisons. However, a case study does provide the actual context of its occurrence in the process of examining a given phenomenon, giving the opportunity to get to know it in-depth, which is determined primarily by acquiring knowledge that takes into account the context in which the phenomenon under study occurs.

The third limitation concerns the limited scope of factors considered in this study. The chosen methods and acquired documents restricted in-depth research and considered problems. Utilising any documents provided by the company may lead to the dissemination of partial and biassed information that may not align directly with the researchers' inquiries. This may also involve a lack of awareness regarding the current status of submitted documents or restricted access to certain documents due to obstruction or refusal to release them. The use of an in-depth form of interview may also cause errors resulting from inappropriate (e.g., biassed) question construction, various types of inaccuracies, or an attempt to show the company from a better perspective or in such a way as to remain anonymous.

Despite these limitations, these results suggest several implications. The results provide unique perspective on the well-researched field of literature. Furthermore, this study provided valuable insight into a highly secure procedure that would not generally be disclosed in a research paper.

In future research, it would be crucial to provide a comparative approach and examine different conditions and strategies for deploying tier-captive SBS/RS systems, as well as critical cases or even the reasoning behind missed investment opportunities. The authors also find it necessary to provide longer periods of WMS (Warehouse Management System) and Kisoft data to provide more reliable efficiency-based conclusions. Furthermore, it would be crucial to include other units that manage the investment implementation process in the research, and to incorporate more advanced methods of data gathering and processing.

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