Impacts of Implementing a High-Density Automated Storage System in a Warehouse

The Case Study of Worten

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Abstract

The retail industry has undergone significant changes in recent years, primarily due to the e-commerce continuous evolution. As a result, consumers are becoming more demanding and expect deliveries to be fast and efficient. In this sense, businesses have globally begun to implement automation in warehouses to increase storage density, throughput, and service level. The current thesis examines the impacts of implementing automated systems in the Worten warehouse, specifically in the area designated for storing low-volume products, which corresponds to 37% of the company's total storage area. Based on the use of a decision support framework already publicly available, the current situation of the company was examined, and the critical issues were identified: lack of space, lack of flexibility in space allocation, low storage density, and picking productivity. Subsequently, an analysis of scenarios with different automated solutions was conducted, followed by a comparison across various key performance indicators (KPIs). The most suitable scenario considered the implementation of a robot-based compact storage and retrieval system. The results suggest that it could represent a 52% reduction in the required space for 2025 and an increase of 9.4% in storage efficiency. Additionally, it would allow for a forecasted 10% increase in the company's service level during the most demanding periods in terms of sales and a 36% reduction in pallet time processing.

Keywords: E-Commerce, Warehouse, Automated Systems, Storage Density, KPIs.

1. Introduction

Consumption trends are changing worldwide, and the Iberian market is no exception. E-commerce had already been growing for a few years, and the COVID-19 pandemic, and consequent lockdown, pushed consumers to make more purchases online. This further accelerated the growth of e-commerce, and this trend is expected to remain in the future. This growth has forced changes in supply chains. This dissertation will explore the case study of Worten, which is a Portuguese retail company that owns the biggest e-commerce site in the country and is expanding the variety of products sold, entering new product categories, which led to an increase in sales, namely on its Marketplace platform. The rise in sales is reflected in the increased quantity of stocked products. It is important to emphasize the significance of the warehouse in the supply chain since, in addition to serving the purpose of storage, it must provide an effective response to the new market challenges. To meet the customers' expectations, some performance indicators must be met. There are new issues that need to be handled, namely in the space management field, considering the increase in the quantity and diversification of stocked products. There is a necessity to optimize the system's productivity, reduce lead times, and answer to demand fluctuations, with enough flexibility to guarantee a good service level. To meet the need for greater storage capacity and quick response, Worten's strategy involves implementing automated storage solutions. Given the growth in the storage of small items, there is a clear need to analyze the possible impacts of implementing an automated solution to store these products. In this sense, this dissertation was developed. The present work also intends to fill the gap regarding the lack of real cases of automation explored in the literature and mainly its impacts on the warehouse in a holistic way.

2. Case Study

2.1. Worten's Warehouse

Worten is the electronics retail brand of a multinational company: Sonae. Nowadays, this retail brand is a Leader in the sector of home appliances, consumer electronics, and entertainment, offering more than six million products in physical or online stores. Worten is currently expanding its offer in several different categories and has also made progress in its Marketplace. The Marketplace is a digital platform where Worten's selected partner companies sell their own products on Worten's website. In addition, the company has been investing in an omnichannel strategy, which consists of a fully integrated shopping experience that connects the physical world - of stores and warehouses - with the digital channels.

Worten's Supply Chain has also been changing over the years. Initially, it was a linear chain, where the products flowed unidirectionally from suppliers to the warehouse and then from the warehouse to the stores. Nowadays, the supply chain is much more complex and dynamic. Worten has one main warehouse in Azambuja, with an area of around 50,000 square meters and 10.5 meters of height. All the sold products pass through this warehouse, totalizing more than 26,000 different stock-keeping units (SKUs). There are two main types of products stored in the warehouse: big-sized products (701), such as fridges and washing machines, and small or medium-sized products (708), such as micro-waves or fans. The warehouse layout can be divided into two main areas: storage and preparation. The storage area is divided into two sections: big-sized and small/medium-sized products. This study is focused on this last storage area.

2.2. 708 Storage and Picking

Since the 708 storage area is under study, it is important to analyzed it in more detail. It comprises three types of storage: drive-in racks (DIN), conventional racks, and narrow-aisle racks. DIN is used for own-brand products that have larger lead times. It allows a higher space usage efficiency since there are no aisles. DIN is placed in one corner of the warehouse because many of its products are stored for long periods. In traditional racks, every product is always accessible. However, it demands a considerable ground area for accessibility. It is composed of active locations in the lower level, where products are picked, and reserve locations, used to stock products in the higher levels. Products stored in this system are placed according to their volumes and weights. Far from the central zone of operations, are stored the biggest and heaviest products, and near the central zone are stored smaller items. Each location is filled with single SKUs (Single SKU location approach), and it is possible to find different types of storage: high pallet, medium pallet, low pallet, shelves, and alveoli. Slow Movers (SM) are stored in narrow-aisle racks. SM are products that are not frequently required. Thus, the quantity stored is low, but the number of SKUs is high. The aisles are shorter in comparison with conventional racks, which results in space saving and more compact storage of the items. On the other hand, both provisioning and picking have lower productivity rates. These racks are located far from the operations area because the slow movers' demand is low. In this type of rack, it is possible to find three storage systems: high pallet, medium pallet, and shelves. Besides the 708 area, there is also the mezzanine where some 708 products are stored. It is used for LAV (High-Value Logistics products) and Fulfilment Products. LAV products are the ones with higher value and smaller volume, considered more prone to be steeled. For that reason, the mezzanine is a restricted access zone. Fulfillment products are sold through the Marketplace. In the mezzanine, there are different areas to store products with different characteristics. The smaller products are stored in racks. In the central zone, the larger and medium-sized items are kept in high pallets. Moreover, roll cages enable the storage of two separate SKUs, each in its layer. The fulfillment zone is composed of racks and alveoli.

Warehouse flows can be divided into two main types: Inbound and Outbound flows. There are different possible merchandising flows inside the warehouse, from which one highlights pick-by-store (PBS) and pick-by-light (PBL). PBS is composed of products that came into stock. It may be a 701 product (large home appliances are always in stock) or a 708 product stored in high pallets. These products are required with no associated order. Contrarily, in PBL, a product is required only if there is a specific order associated. Worten adopts a cross-docking strategy to deal with these items. Therefore, there is no need to keep stock of PBL items.

Regarding the picking processes, a wave-picking strategy is adopted. The management releases waves accordingly with the distributor that will deliver the orders. After the release of a wave, Worten utilizes two main picking strategies that correspond to the PBS flow: bulk picking and batch picking. The picking method used for PBL products is bulk picking. With bulk picking, one SKU is picked for all the stores it was requested. The SKU is stored in its picking location, and the picker moves with a forklift and an order with all the units needed for that SKU for all the stores. The separation of products by store only occurs later in the process. Batch-picking is the method carried out to pick 708 products stored in the active locations. It requires an operator to use an electric pallet truck with two pallets. Each one corresponds to a specific store, and the operator follows a pre-defined track, loading the pallets with the ordered items. The organization, from the heaviest and biggest products to the smaller and lighter ones, facilitates the process of building the pallet, increasing productivity. Pallets are then sent to the wrapping zone before moving on to the outbound docks. The picking of mezzanine products is performed following a circuit, as happens in the 708 area's racks.

2.3. Problem Statement and Objectives

Worten has been facing logistical challenges in its warehouse due to the increasing demand for its products, driven by a rise in Spanish sales, online demand during the pandemic, and growth in Marketplace sales. Additionally, Worten's strategy of expanding its range of products and services has resulted in a diverse inventory with different characteristics such as size, volume, stowability, and weight. Thus, the company's stock has increased both in the quantity of products and in the number of SKUs stored. However, the limited space in the warehouse has made it difficult to accommodate these products. Therefore, Worten aims to increase efficiency in the storage of products without investing in expanding the warehouse space. To address this issue, the company intends to implement an automated storage solution that increases the storage density of 708 products.

The main goal of this project is to assess the impact that such implementation would have on the warehouse. The project aims to contribute to solving Worten's space management issue by studying different automated solutions that may increase the storage density and optimize the space utilization of the warehouse. It is intended to identify the products or families of products (according to their depth and width, weight, among others) that are suitable for the proposed storage system. The project will also assess Worten's requirements for the proposed solution to analyze the feasibility of implementing such equipment. The impacts of the new system will be assessed in different areas, such as space management, systems' throughput, and workforce requirements. The most suitable solution for Worten's reality will be proposed and compared with the As-Is model for 2025, regarding different key performance indicators (KPIs).

3. Literature Review

3.1. Warehouses and Automation

Market conditions have been changing over the years. With increased trade, the number of warehouses and the space used for warehousing has grown rapidly [1]. The main downside associated with traditional warehouses is that they occupy much land and infrastructure. Automated systems allow for a reduction in storage space, which is important due to the increasingly limited availability of land [2]. The need to accommodate growth was identified as the main reason for companies to adopt automation. Moreover, the increase in e-commerce, mass customization, and omnichannel distribution are other identified factors [3]. Warehouse Managers are realizing that manual resources have reached the limits of their productivity levels. Automation allows to achieve the necessary throughput at high levels of speed and accuracy whilst maintaining costs at an acceptable level [4]. Therefore, operating procedures of warehouses have seen significant changes, pushed by the increased customer service standards; greater number of SKUs stored; the necessity to improve space utilization, and warehouse operating efficiency. The biggest difference between automatized warehouses and traditional ones is that in automated warehouses the manual intervention is reduced as much as possible to improve processes' efficiency [1]. In these warehouses, a number of programmed instructions convert manual processes into automatic ones. Some of the disadvantages associated with traditional warehouses are identified in the literature: over-handling material; damaged materials due to human accidents; inefficient materials handling equipment; and inefficient space management [5].

It is crucial to comprehend the drivers of service level to correctly manage performance, which is becoming more relevant as it influences customer decisions [6]. Different KPIs concerning warehouse operations were identified, from which it is possible to highlight receiving and shipping productivity, put-away and picking cycle time, and storage utilization [7]. In that sense, the effects of adopting automated technologies are reflected in higher customer service levels and reduced lead times [8]. The lack of flexibility and the high initial investment are the most common reasons for resilience when it comes to implementing automated systems [3]. Nevertheless, its implementation continues to rise over time [4].

3.2. Automated Storage Systems

New automated technologies like high-density storage systems are receiving more attention. These systems are defined by the occasional need to move interfering items to reach the desired ones, providing high space utilization efficiency [9]. Automated methods are key components of automated warehouses due to the high throughput and storage capacity [10].

Automated Storage and Retrieval Systems (AS/RS) operate with speed and accuracy and are a crucial component of the picking system. It was proved that bringing the inventory to the picker can double the picker's productivity [11]. The study will be focused on different types of AS/RS: conventional AS/RS with forklifts/cranes, shuttle systems (both Aisle-based and Grid-based), and Robotic Mobile Fulfillment Systems (RMFS).

An AS/RS with forklifts/cranes is composed of storage racks erected along aisles with cell conveyors, input/output (I/O) stations, and storage/retrieval machines to transport products between I/O stations and storage cells [3]. It is installed in the picking aisle for reaching the storage cells. To perform a storage operation, a crane picks up a load from the conveyor and stores it in the racks. The retrieving occurs in the reverse way. Two classes of AS/RS were explored: (i) Unit-Load AS/RS - stores pallets, (ii) Miniload AS/RS - stores totes. Shuttle-Based Storage and Retrieval Systems (SBS/RS) are characterized by using shuttles to operate the horizontal movements within the tiers, on any level in the aisle, and lifts to operate the vertical movements. Lifts may move products/totes/pallets between tiers [1], [12], [13]. To retrieve a product, the shuttle moves to its storage location, picks it up, and moves it to the lift. Then, the lift moves to the lower level and leaves the product in a conveyor to be transported to the pick station.

Two types of Grid-Based Shuttle Systems were explored: Live-Cube Compact Systems and Robot Based Compact Storage and Retrieval System (RCSRS). In the first system, a lift transports the shuttles between different levels of grids until they reach a depot [1], [12]. Products are stored in a grid with at least one open location. To retrieve an item, an open location is first moved next to the requested product, through a set of movements between full locations. Then, an open location is used to move the item to the I/O point. To store a product, the procedure occurs backward. With RCSRS, robots transport and store products, that are kept in a grid-topped storage stack. Totes that contain the items are placed on top of each other, forming the storage stacks. The workstations are located at the lowest level next to the storage stacks [12]. Each cell of the grid corresponds to the entrance of a storage stack. The lifting-capable robots roam on the grid and extract totes from the storage frames.

RMFS is composed of autonomous guided vehicles (AGVs) that are capable of following prescribed paths [3]. RMFS make use of robots to lift and carry movable shelves to retrieve the storage pods from the storage area and transport them to the pick stations. When an order is placed, it is assigned to a workstation and then the product is assigned to a pod and a robot. The robot moves, without load, towards the pod to retrieve it. Once the robot lifts the pod, it is transported through the travel aisles. Then, the robot brings the pod and enters a workstation buffer and queues for its turn. Finally, the pod is stored back in the order pick area. Each workstation has one worker who picks the products and adds them to the order totes [12].

3.3. Literature Gap

Throughout the literature review, the need for a holistic analysis of warehouse operations became apparent. This gap has been highlighted by several writers, encouraging further research in this direction. The lack of research regarding inbound logistics was also mentioned [14]. Thus, this study also aims to fill this gap, evaluating performance indicators for inbound processes. Another gap was the little direct evidence of collaboration of the academic research community with industry [15]–[17]. More industrial case studies are required, in order to help the warehouse research community better comprehend the current problems with warehouse design [15]. Scientific literature reveals a need for more studies to confirm the advantages of automated systems through a case study using both qualitative and quantitative data [18].

4. Framework Proposal

It is important to follow a framework, not only to apply an automated solution in a currently non-automated warehouse, but also to measure its impacts, this being the focus of this dissertation. Therefore, in this chapter, a framework (Figure 1) is proposed to be adopted during the following section. The main goal of the framework, presented in in the paper "Warehousing process performance improvement: a tailored framework for 3PL" [19], is to aid in the deployment of effective performance improvements, resulting from the knowledge of the observed warehouse.

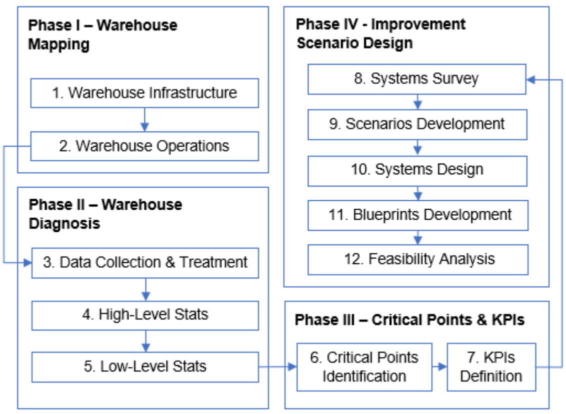

Figure 1 Proposed Framework | Adapted from: [21]

As it was initially conceived for non-automated 3PL warehouses and is not usually adopted to study the implementation of automated solutions, some adaptations were made to the original model. The framework followed, that is presented in Figure 1, was obtained after the adaptations. It is composed by four phases.

Phase I - Warehouse Mapping: the major objective is to obtain an overview of the current system. To achieve this, it is crucial to analyze both the warehouses' infrastructure and operations. Different tasks are described for both areas of analysis. This phase entails an initial inspection of the warehouse with on-field observation of the storage system and the workflows.

1. Warehouse infrastructures: general system presentation regarding the current company's infrastructure and layout. Identification of the type of products under study. Identification of the company's storage assignment, routing, and picking policies. Presentation of the plant of the research area, as well as the control points (CPs) and system's features (racks, aisles, etc.).

2. Warehouse Operations: processes flow charts presentation. Distinction between handling, pause, storing and control processes. Activities' time measurement.

Phase II - Warehouse Diagnosis: focuses on data gathering and analysis. Its main objective is to measure the flows previously defined in phase I over a defined timeframe.

3. Data collection and treatment: data was collected from the WMS and treated in Excel and Power BI.

4. High-Level Stats: comprehension of the systems' main characteristics through the data analysis over a timeframe. These metrics seek to obtain general metrics (such as the average level of inventory, or the number of SKUs)

5. Low-Level Stats: establishment of a period that accurately represents the warehouse processes under study and exploration of the tendency of different metrics throughout the previously defined time horizon.

Phase III – Critical Points & KPIs: starts with the identification of room for performance improvement according to the analysis of the data collected in the previous phases. It is divided into two tasks:

6. Critical Points Identification: the sources of inefficiency are identified and described.

7. KPIs Definition: has as a major outcome a tailored panel of performance metrics for the warehouse under study.

Phase IV - Improvement Scenario Design: aims to design the improvement scenario that better addresses the panel of KPIs.

8. Systems Survey: the literature is explored to find the existing approaches, to cope with the identified KPIs.

9. Scenarios Development: the creation of the most suitable scenarios for the company.

10. Systems Design: systems are designed, according to the company's specificities.

11. Blueprints Development: the prototypes of the different scenarios are created.

12. Feasibility Analysis: scenarios are tested in order to choose the most suitable one for the company reality.

5. Framework Implementation

5.1. Phase I: Warehouse Mapping

The framework will be applied exclusively to the areas and processes related to the 708 area. The first phase's objective is to better understand the current warehouse configuration. From an initial inspection of the warehouse, it is possible to provide an overview of the systems. The plant of the study area, regarding the processes applied to the 708 products is presented in Figure 2.

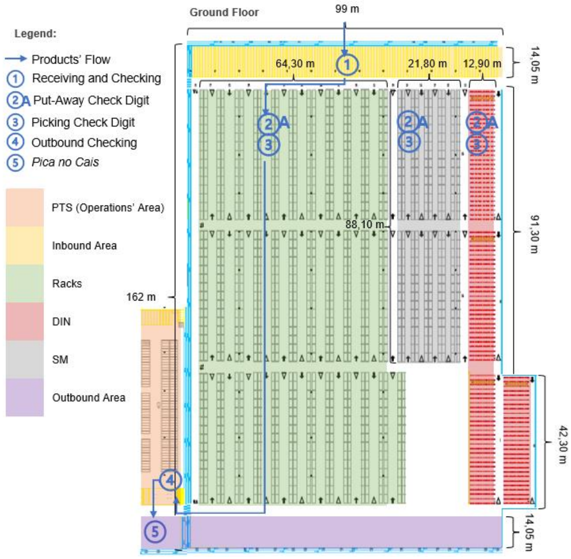

Figure 2 708 Storage Area Layout

The main control points are highlighted. This set of control points ensure that, when shipping, the products registered in the system are going out and that the WMS is in accordance with the reality of the warehouse. Regarding the system layout monitoring, it is possible to see the representation of regular racks, narrow-aisle racks, DIN, as well as their length and width. The remaining space is made up of aisles, inbound and outbound areas, etc. Regarding the workflow, the directions of movement in the aisles are also highlighted in Figure 2, as well as illustrative examples of the products' routes, passing through all the control points. Picking is the most time-consuming process. This current reality can be, most likely, changed with the implementation of a parts-to-picker system.

A set of high-level metrics was calculated to comprehend the system's behavior. The selected period ranges from January 1st, 2022, to December 31st, 2022. Concerning the number of products and SKUs stored per storage type, DIN stores a low number of SKUs, but a considerable quantity of items, because Worten's own brand products consist of a reduced number of references that come in large quantities. On the opposite side, slow movers have a higher number of SKUs, each one stocked in reduced quantities. It was observed that the overall stock increase was primarily due to an increase in SM and fulfillment items. The fulfillment area has been growing and its mezzanine space tends to grow over time. Slow movers have also grown, since the large number of references kept increasing as a direct result of the variety of products now offered.

Two moments were selected to proceed with the low-level metrics analysis, one day of low-demand season (April 20th) and another of high-demand season (November 20th). November displayed higher values in terms of both SKUs and the quantity of products stored. The SKUs revealed a reduced oscillation between own brand products and supplier products from April to November. In terms of stored quantity, the majority (59%) was own brand in April and shifted to supplier brand (51%) in November. The growth of supplier brand products was due to the Black Friday, when a greater variety of items was sold, some of which do not sell during the low-demand season. The average storage utilization rate and the location utilization rate were analyzed. The main takeaway from the analysis of the two metrics is that both values were low. In the first case, it frequently went below 50% and never exceeded 60%, and in the second, the highest value was around 64%.

The critical points present in the currently adopted system, that may be improved in the future, were identified. Firstly, the lack of space needs to be addressed, as almost all the storage space is being used and the storage density is reduced. Knowing that the stock volume is increasing, it will most likely lead to a lack of space in the warehouse. In addition, manual put-away is compromising the warehouse's organization. The honeycombing effect is another issue: several available locations are not being utilized, due to the fixed picks system adopted. This method can be problematic due to the lack of flexibility in space allocation. The need to store some products separately (in the mezzanine) requires more space and different processes associated with the picking process. It comes with a decrease in the process productivity. The low picking productivity in SM is another critical point. Finally, the distinction in active and reserve locations comes with the need for replenishment, a repetitive and time-consuming task. Besides, it is necessary to ensure sufficient ground-level locations for all SKUs.

The next step was to define the most relevant KPIs to be analyzed. Table 1 presents the KPIs to be considered, as well as their respective definitions, and the dimensions they have an impact on.

Table 1 KPIs and their dimensions

Dimension: Time
Put-Away Tyme; Order Picking Time; Pallet's End-to-End Time; Required Full Time Equivalent (FTE)
Dimension: Quality
Damaged Products
Dimension: Productivity
Occupancy Rate; Effective Storage Space; Storage Efficiency; Storage Utilization Rate; Products Stored in Automated Systems; SKUs Stored in Automated Systems; Throughput; Automated Systems Location Utilization Rate; Average Number of Products per tote (or per pallet)

The high-density automated storage systems that had been previously selected in the literature review were further analyzed: AS/RS with cranes/ forklifts (Unit-Load and Miniload) were discarded for having larger aisles, when compared to SBS/RS, which results in a reduced use of space to store products (lower storage density). SBS/RS (Unit-load and Miniload) allows for the number of shuttles to be changed according to the warehouse needs. This has implications for the throughput capacity, which is higher as the number of shuttles in utilization increases. Besides, SBS/RS has a lower retrieval time than AS/RS with cranes/forklifts, so SBS/RS will be considered in the study. Live-Cube System was discarded for having a fixed number of non-adaptive locations. Contrarily, RCSRS allows the number of locations to be extended over time. RMFS were discarded for having a two-meter maximum height. The available height of the warehouse is 10.5 meters, so the implementation of this type of system would result in a considerable waste of vertical space. Summarizing, the study will focus on three systems: Unit-Load SBS/RS; Miniload SBS/RS; and RCSRS. Based on these systems, six scenarios were developed. Scenario As-Is is the warehouse's current situation. The remaining scenarios are predictions for 2025. Scenario 0 assumes the maintenance of the current storage systems. Scenario 1 considers the implementation of the Miniload SBS/RS. In Scenario 2, the warehouse combines two automated systems: a Unit-Load SBS/RS, and a Miniload for the remaining items. Scenario 3 combines a Unit-Load SBS/RS and an RCSRS (AutoStore). Scenario 4 considers the implementation of the AutoStore system.

The procedure followed to obtain the scenarios started with the data treatment and ended with the discovery of the number of handling units to be stored in each system for all the scenarios. Firstly, the forecasts for the quantities of products and number of SKUs to be stored were made. For DIN, the steps followed were the same for all five future scenarios: the total quantity of products was added up by SKU. It was then divided by the products' TiHi for each SKU, to determine how many high pallets were stored. Based on the predicted increase in products' quantity, the new number of high pallets was estimated.

Regarding the remaining systems, to facilitate description of the process followed, the diagram in Figure 3 provides the key steps taken to determine the number of locations that will be required for each system, in 2025. For scenarios 2 and 3, the products that are currently stored in high pallet racks will be stored in the pallet system, according to the process described in the orange box. From this point on, the processes are similar for Minioad and AutoStore, in their respective scenarios: the dataset was filtered to keep the products that fit the admissible dimensions and weight of each system, to determine the products that will be stored inside it. Note that the admissible dimensions and weights differ between Autostore and Minioad. All the AutoStore products are stored in totes, while items stored in Miniload can be of two types: high volumetry, if the volume of the product is higher than 50% of the tote's volume, and low volumetry otherwise. High volumetry products are stored individually in a location, while the other ones are grouped in totes before being stored. For products individually stored, every product has a corresponding location. Hence, the number of future locations corresponds to the number of products to be stored. For products stored in totes (both for AutoStore and Miniload systems) the process is described in the green box. For high pallet products and remaining location types, the procedure is described in the purple box. The required number of future locations was calculated based on the predicted evolution in products' quantity.

In Scenario 0, products are stored in conventional racks, with the difference that high pallet products are distinguished (rack, SM, and mezzanine) and treated separately, because the SM zone and rack zone are apart. Plus, it is impossible to maintain the separation between reserve and active locations, as it would require more space than the one available.

It was necessary to develop the warehouse's blueprints for each of the six scenarios. For the As-Is scenario, the number of locations occupied was given by Worten. For the other scenarios, the number of locations was predicted. Scenario 4 was considered the one that better fulfilled Worten's needs. Its blueprint is presented in Figure 4.

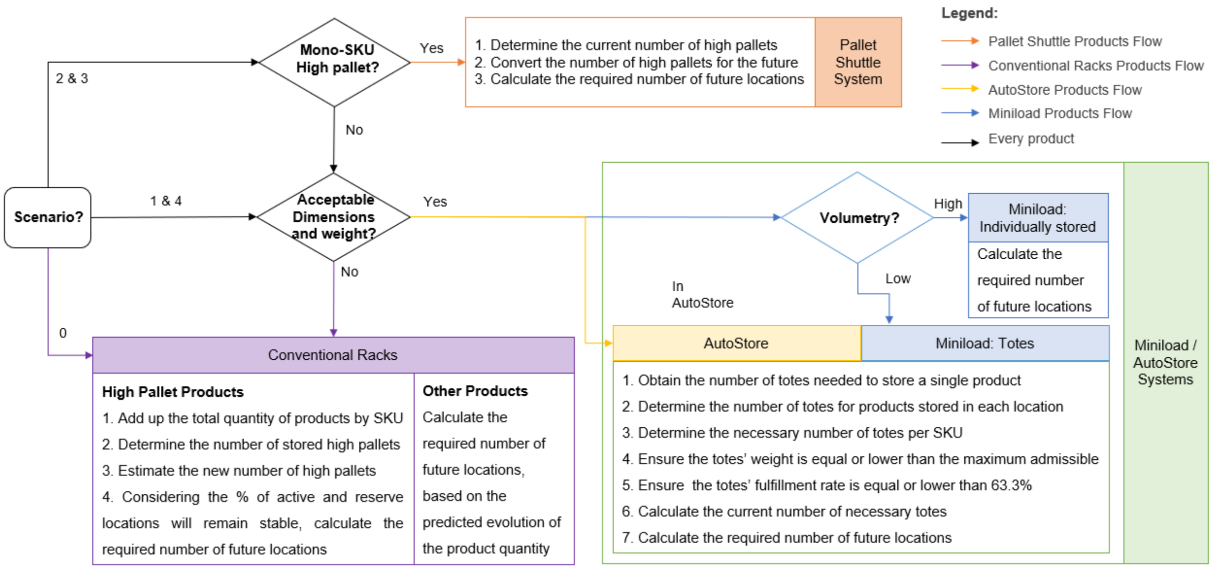

Figure 3 Procedure to Determine the Number of Future Required Locations

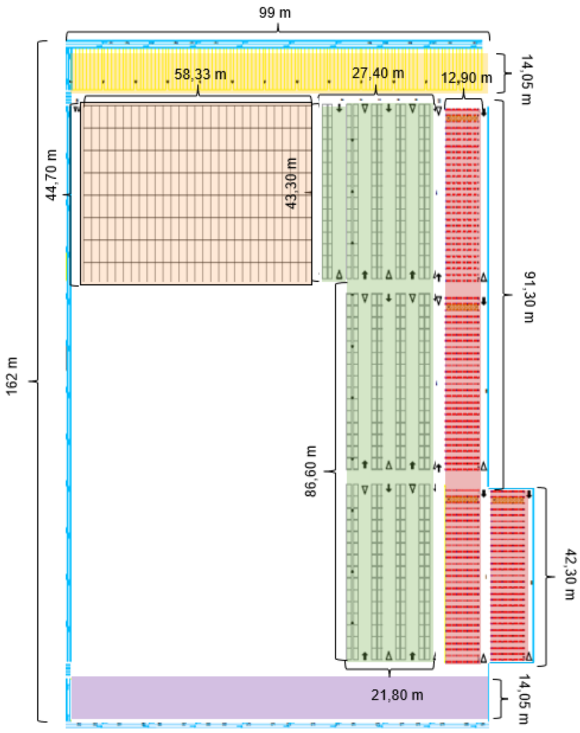

Figure 4 Prototype of the Proposed Scenario

The proposed scenario was analyzed in more detail and compared to the As-Is solution and Scenario 0 – designated as a future scenario. The lack of space is the main driver of Worten to adopt a different storage system. So, the analysis starts with the following KPIs: occupancy rate (Figure 5) and storage efficiency (Figure 6).

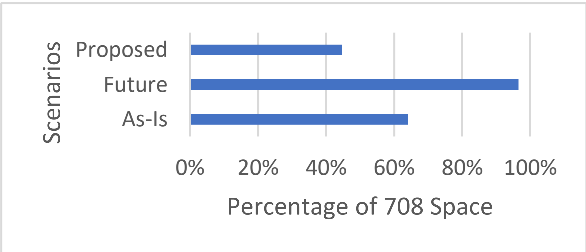

Figure 5 Occupancy Rate in each Scenario

The warehouse's occupied volume will increase by 33% in comparison to the As-Is situation if the current storage systems are maintained in the future. The storage efficiency, which is naturally reduced in conventional systems, is around 53%. This means that only 53% of the total rack space would be available to receive stock. Thus, more space would be necessary, and that space would be less effectively used if no automation is implemented.

The proposed scenario is the most advantageous option, as is the one with lower space requirements (45%) and higher storage efficiency (62%). Its average storage utilization rate corresponds to 52.8%, which is greater than the current rack system's percentage (where high racks have the higher occupation with 52.2%, and the remaining racks fall below 20%). For AutoStore systems, the location utilization rate is almost 90%. It is higher than the As-Is scenario, where it is usually below 60%.

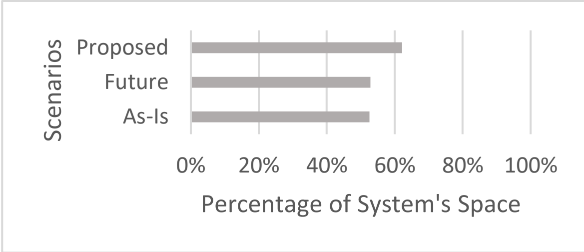

Figure 6 Effective Storage Space in each Scenario

Table 2 presents the distribution of stock by storage systems, the throughput for each of the systems, the work-related requirements, service level, and pallets end-to-end time. Starting with the throughput, the As-Is scenario has the lowest one. Both As-Is and Future scenarios show the same throughput for the rack system. The variation lies in the number of existing racks. The considered throughput was obtained from the current picking productivity of 1.8 minutes per item.

Table 2 Comparison Between Scenarios

	As-Is	Future	Proposed
Product in racks	100%	100%	8%
Maximum Throughput	1100 units/h	1100 units/h	3300 units/h
Service Level	90%	55%	100%
Required Workforce	105	165	139
Pallets' End-to-End time	2h20/pallet		1h30/pallet

This assumption that the throughput remains constant when the number of racks decreases implies a variation in the number of pickers proportional to the reduction in rack locations for each scenario. Automation would also bring benefits in terms of time. This is because the future scenario has only one type of storage for all products, which is the one with the lowest throughput. AutoStore proves to be more efficient. It can reach a maximum throughput of 3 300 products/h, considering the availability of 132 robots. The number of processed items on Black Friday of 2022 accounted for 90% of all the orders' products for that day. In the future, it was assumed that productivity would remain equivalent to the As-Is scenario. Racks were not considered for the proposed scenario, as they represent a reduced percentage of stored items.

Based on the analysis of the future scenario, the order processing capacity on Black Friday will decrease from 90% to 55%. Lastly, the analysis shows that AutoStore's throughput will not be a limiting factor for the company. For the proposed scenario, during Black Friday, it would be necessary to utilize 14 workstations and 132 robots for picking. However, for low and medium-demand seasons, these values can be reduced.

One of the clear benefits of AutoStore is its high flexibility due to the ease of expanding the number of locations or the number of robots if the business demands it. As mentioned, the current demand patterns and the growth of e-commerce make this factor a key element for Worten. To sum up, the results achieved with the AutoStore system allow for high picking throughput, improving the footprint usage and a high storage density. It is anticipated that the required number of operators will rise to 165, which consists of a 57% increase over the current number of workers. Besides the additional costs for the company, this could result in issues related to a lack of workspace. In the suggested scenario, a workforce of 139 employees should be enough to ensure the warehouse's operations. There is an expected reduction from 2:20h to 1:30h in the pallets' end-to-end time. It represents a 36% reduction in the time it takes to process a pallet of products. This result may contribute to Worten's objective of transitioning to a "same day delivery" policy instead of the current "next day delivery".

AutoStore also solves a lot of operational issues: picking productivity will be improved because batch picking is restricted to products stored in racks. The end of the narrow aisles will also contribute to that improvement. AutoStore independently organizes its locations, so the product's location changes in a completely dynamic way. This will end with the current fixed-pick system. The empty locations caused by the lack of the product to which they are assigned cease to exist and are automatically assigned to another SKU that is in the warehouse, avoiding the honeycombing effect. This solution also solves the manual put-away issue, because the system itself is responsible for allocating products to their correct locations rather than requiring human intervention. Additionally, it is the end of the distinction between active and reserve locations that created a struggle regarding the available ground space. The increase in the number of mezzanine products is no longer a problem, as there is more available space, and the system is expandable. Besides, Fulfillment and LAV products already do not require to be stored in a separate area.

6. Conclusions and Future Work

Worten requires improvements in its storage management for low-volume products, due to the increasing level of inventory that is being held. To approach this issue, the current storage systems were described, and potential automated systems to implement were identified, as well as their main characteristics. It was concluded that there were some noteworthy gaps in the literature concerning the impacts of automated systems within a warehouse: there was a need for a holistic approach to deal with the consequences of implementing automated systems in a warehouse, particularly focusing on inbound processes. In addition, a gap was identified between the academic research on this topic and its practical applications in the industry, highlighting the relevance of this work. A decision support framework [19] was adapted and applied to the case study. Through this application, the As-Is Scenario was explored, as well as the available data, regarding the warehouse's storage area. Subsequently, relevant KPIs were defined, and five predicted scenarios for 2025 were created, and later tested, each one involving different storage systems. The proposed scenario consisted of the implementation of an RCSRS. It could represent a 52% reduction in the required space for 2025 and an increase of 9.4% in storage efficiency. Additionally, it comes with a throughput that would allow for a 10% increase in the company's service level during the most demanding periods (Black Friday 2025). Finally, it could reduce by 36% the time it takes to process a pallet of products, contributing to Worten's strategic goal of implementing a "same day delivery" policy. The main contributions of the present work consist of the application of a tailored framework for the implementation of automation in a warehouse; the proposal of a customized solution that fulfills Worten's requirements, and the exposition of the impacts across the warehouse's processes. Therefore, it can be considered that the objectives of this study were achieved, and hopefully it will contribute to Worten's future strategy and for the scientific community.

Finally, some suggestions for future studies, that may bring valuable insights on this topic, are provided. A more detailed analysis could be performed, regarding the SKUs storage methods, considering different storage policies (class-based approaches, for example) and their respective consequences in terms of throughput and operations. Another area of research that could be delved into is the automated systems' impacts on workers' interactions, as this topic constitutes a gap in the literature that has been increasingly explored recently. Sustainable operations is another field that still requires more research, particularly in the inclusion of environmental related metrics in warehouse management [14]. Future studies could give continuity to the developed work by including this topic. Similarly, cost optimization can be considered, as this project could serve as a basis for obtaining a scenario with optimized costs. Other metrics could be used to determine which products are stored in the automated systems, such as the item's popularity and cube-movement, instead of only considering the item's dimensions and weight.

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