Design of a Structure for Big-sized Appliances in a Warehouse

The Case Study of Worten

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Abstract

Nowadays, the retail sector faces daily challenges and constant change. In order to keep up with a growing market and be a top competitor, it is necessary to stay one step ahead in terms of competitive advantage. Factors such as: improve consumer experience in order to make it even more personalized, offer a wide range of products, operate an efficient and effective distribution network taking advantage of economies of scale, integrate a service ecosystem, and investing in conscious and decisive improvements integrating a multichannel network are some examples. One of the main points in a supply network is the warehouses, which are responsible for receiving, picking, storing, preparing, and sending the desired products in the appropriate way. Storage needs have increased, it is therefore essential to redesign the layout of certain critical areas in order to be able to store larger volumes in the most efficient manner, while also making the operation capable. This paper, aims to study and provide a design solution for the improvement of the storage area of the big-sized appliances at Worten. The design should aim to be the most efficient as possible, managing to get the best trade-off between storage and its respective investment and associated costs.
Keywords: Warehouse; Block-staking; Storage Design; Storage Sizing; Simulator; Cost-benefit Analysis.

1. Introduction

Worten, one of the top 3 leading retail companies in Portugal, supplies its entire supply chain through its central operations warehouse based in Azambuja, Portugal. The company now operates in the Portuguese and Spanish markets, with the goal of expanding internationally, further broadening its product offering. The disruptions in the supply chains since the beginning of the global pandemic, and the recent war in Europe, make it increasingly difficult to consolidate the growing needs of the company in terms of space. These factors lead to often unexpected peaks in merchandise receptions, with the need to stock more products in order to ensure sales and always guarantee supply to the stores and the end customer. Nowadays, the company rents space in three geographically different external warehouses in order to make up for the deficit of space in its own warehouse, mostly in the department of big-sized appliances. Therefore, the company needs to rethink the layout of its own warehouse area, in order to find the most profitable system to store products of this typology, taking advantage not only of the entire solo area, but also the full height of the space. Adding to this challenge, the desire of keeping an increasingly efficient operation in order to meet the everyday orders, always aiming to reduce it´s lead time, companies´ fixed and variable costs.

2. Case Study

2.1. Problem Definition

The central point of all flows is Worten's warehouse in Portugal. So, it is increasingly necessary to seek cost-effective ideas to keep up with all the growing demand and also the ever increasing consumers' demand in a ever fast changing world.

The sales of big-sized appliances at Worten have been growing steady over the last few years. The stock level of this type of items has increased as well as the number of SKUs[1]. As a result, one of the most critical areas of the warehouse is undoubtedly the 701 solo. This is due to the current impossibility of storing as many products as possible up to the ceiling. The stacking factors of this typology of products are relatively low, in order to prevent damage. Even with products with higher stacking factors, about half of the warehouse footprint remains unoccupied, resulting in a significant loss of storage locations, density and the fact that Worten is "paying for storing air" since that space is never filled.

2.2. Warehouse Description

In Portugal, the Worten operation is solely and exclusively supplied by the Azambuja warehouse. This is the starting point of the distribution for all the points of sale and final consumers including the Iberian Peninsula and the Canary Islands. The warehouse has around 50.000 m^2, and operates

[1] Stock Keeping Units

16 hours a day, 7 days a week.
In terms of different SKUs types in the warehouse, there is a first differentiation based on the dimensions of the products. The 701 items left side of figure 1 are larger products, called big-sized appliances, from refrigerators to washing machines. These items are more difficult to handle due to their volume and also the type of storage characteristics required presenting greater restrictions.

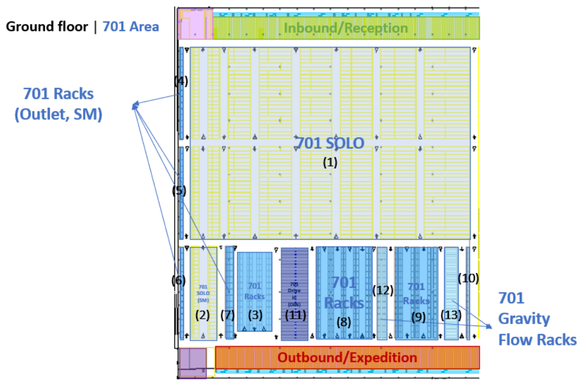

Figure 1: Azambuja Warehouse Overview regarding 701 areas

Big-Sized Appliances (701 area)

It will be explained in detail the different types of structures that the warehouse has at the moment, regarding the area of focus destined to big-sized appliances.

The largest area of the entire space surrounding 701, is the "solo", with 11290.87 m^2 in total, about 25% of the entire warehouse solo floor, with a useful storage area of 8513.39 m^2 discounting the circulation aisles. In this area, items are arranged in block stacking. Although this storage typology is cost-efficient, it is not the most efficient in terms of space usage and operation productivity. There is a limitation given by the product stacking factor, which means that the space can only be used up to a limited height, requiring large extensions of floor space when aiming to store large amounts of stock. Also, this storage method, as it currently is displayed does not make use of all the warehouse height.

2.3. Warehouse Operations regarding 701 area

Inbound Operations

When entering the perimeter of the warehouse, the truck is registered at reception and directed to the dock designated for unloading. The truck driver must break the seal on the semi-trailer so that the operators responsible for unloading can be sure that the goods have not been tampered with or opened during the journey, otherwise the goods cannot be trusted and will not be accepted. The quality control team accompanying the unloads has a priori a list of the trucks and goods to be inspected (a study made previously by the administrative office, sales team and customer service department). When a truck arrives that is going to go through quality control, an inspection is made based on a certain percentage of the total goods in a non-linear manner. The goods are received, with the help of a device PDT[2]. At this point, iLPN[3] is created according the quantities that are to be stored together.

Storage Operations

Regarding storage operations there are three main activities: put away, compacting, and replenishment. Put away is a follow-up to the check activity. When the reception of goods is finalized and the ASN[4] is closed, the goods are ready to be put away. The operator reads the iLPN of the items with the help of the PDT and it provides the locations where there are such items like the one read, then put away activity is performed. Compactations is an activity only carried out in the 701 solo area, with the goal of making it possible to group same items in order to occupy fewer locations, increasing its percentage of occupancy and freeing up new spaces for future supplies. A dedicated storage policy is used.

Storage Properties of 701 solo

In the study area 701 solo, the locations are formed by rectangles and squares drawn on the floor with different dimensions and accessed by an aisle. In this area, there are 23 locations with different dimensions designed to store items with distinct properties, volumes, and quantities.

This solo storage system has reduced efficiency, which location can only hold one SKU at a time. Only when all those units of a single SKU have been removed from that lane, it becomes free to be occupied by a new one. When put away is done, a location is assigned on the solo, always dependent on the quantities already in stock and those that are entering the system and need to be stored. Always with a view of each location having the highest percentage of occupancy possible, this ratio named occupation efficiency is obtained by dividing the real occupied space by the location area. The particularities described is a phenomenon called honeycombing and occurs because there is only one SKU in each lane. This issue gives origin to free spaces when the location is less occupied, which means that when the picker wants to go to a particular product location does not have to move others to access or to retrieve. There is a trade-off between storage and handling efficiency, and in this instance, the fewer items moved, the higher is the handling efficiency.

[2]Portable Digital Terminal
[3]inbound License Plate Number
[4]Advanced Shipping Notice

Outbound Operations

Regarding the preparation of orders for 701 products, there are two[5] ways in which these can be dispatched: through PBS or SCED. When orders follow a PBS flow, it means that during picking, the items are placed on pallets by store, and may be done in batch picking. An operator can only process one or two orders from different stores at the same time due to picking capacity limitations. Before being ready to be loaded into the truck, the pallets are wrapped and left on the outbound area. If the flow to be followed is through SCED, which means that the orders are collected for consumers to be delivered directly into their homes. Only one picking is done at a time because the SCED does not compile products onto pallets, as they are sent in bulk. When the picking activity is finished, the products are left on the loading lines but in the reception area.

3. Literature Review

3.1. Warehouse Structures for Big-Sized Appliances

As is system, Block Stacking

A block stacking is a unit load storage system where products are stored in several piles on top of each other, on the warehouse floor, stacked to the maximum height allowed, between aisles. Considered factors for stacking the goods are: heights, load weights, safety restrictions and warehouse clearance height. This kind of system is common in warehousing and it is an inexpensive storage technology whose effectiveness is calculated by the efficient utilization of space, [10]. This method allows to store large quantities, [9], in a warehouse with a wide floor area and/or a high ceiling, however, is not a light challenge the process of space planning. One of the advantages of this system is that no structure is needed, which makes it very low on costs, [9]. To control storage space in this kind of system, it is normally adopted a dedicated or a shared storage policy. This type of storage policies carries some responsibilities in terms of SKU organization. Only one SKU per location can be stored, when taking advantage of a dedicated policy, [10].

An equally significant aspect respecting this storage system, is that can achieve a greater number of items stacked per m^2 relative to the percentage of floor space occupied, [6].

Structures and Systems to Consider

Over the years with the development of technologies, the actual use of high-density storage devices has evolved. There are two[6] inventory management policies that can be applied to the types of structures to be treated, FIFO, and LIFO, [22]; [16].

The system using a FIFO storage policy is mostly used in food and pharmaceutical industries where shelf life is of great importance. In this case, products are put away through one side of the structure and removed from the opposite side. A LIFO policy, on the other hand, uses the same side of the structure for both put away and picking. In this system, it is not relevant that the first product is the first product out. Often, when the policy to be implemented is not important, the type of system that is required is firstly considered, and only then the most appropriate policy is determined, [22].

Structures and/or systems based on the literature review (the most important two articles used were [21]; [22]), that could be considered for storage of large products, such as big-sized appliances are: Drive-in and Drive-through Racking; Satellite, or Shuttle Racking; Push-back Racking; Adjustable Pallet Racking; Narrow-aisle Racking and Gravity Flow Rack.

Only the type of structure below, platform/mezzanine is explained in detail, because it is the only one that can be used together with any of the other types of systems mentioned previously.

Platform/Mezzanine

Platforms also called Mezzanines, are the best solution on the market to be able to take advantage of unused overhead free space. This allows the operationalization of resources, making them more efficient and profitable. A platform in a warehouse may contemplate several types of operations and uses, defined by the dimensional increase of storage space, which is not possible to make profitable in any other way. This type of solution is normally used in places which have relatively high or very high ceilings, and where the intention is to make the most of all the space, not "paying for air", allowing the useful area to be doubled as many times as possible, making the most of the height. This type of structural solution has a wide range of optional materials, which allows the company to adapt and customize 100% to the company needs. This storage system, comes from the needs previously mentioned, of the impossibility of adding another building or grow the space in terms of solo. More obvious advantages of this typology, is that on it can be applied any type of storage system and becoming a versatile solution, [1], [2].

3.2. Design Validation

The two methods chosen are simulation, which is widely used nowadays to experiment with various scenarios in a non-invasive way the warehouse operation, and cost-benefit analysis. Regarding the last evaluation method, two[7] primary indicators

[5] PBS - Pick By Store; SCED - Complementary Service of Home Deliveries

[6] FIFO - First-In, First-Out; LIFO - Last-In, First-Out

[7] ROI - Return on Investment; PP - Payback Period

are used regarding monetary calculations, ROI and PP.

Simulation

Simulating the behavior of a real world process or system over time is known as simulation,[5]; [20]; [13]. Simulation creates an artificial history of the system and observes it to conclude the operational characteristics of the real system being studied, over time, [5]; [20]; [13]; [18]; [19]. For many real world challenges, a simulation is an essential approach to effective problem solving. Simulation is used to explain and analyze the behavior of a system so that it is possible to ask ”what if” questions, and also to help in the design of systems to be implemented. The level of congruence between the real system and the model is determined taking into account its objectives and the simplifications in the design, [8]. Simulators can be used to represent both existing and hypothetical systems, [5].
Simulation allows users to create a representative model of reality, even if approximately, by experimenting with different scenarios with different inputs without constraining or disturbing the functioning of the real system. This is all possible before committing resources to a project, evaluating and comparing options and their viability, [13]; [7]. For all the factors mentioned, simulation is a method to validate models regarding warehouse operations, [4]; [12].

Cost-Benefit Analysis

A CBA[8] is based on fundamentals of economics welfare and public finance, which offer a theoretical framework, allowing according to society's point of view, to identify and evaluate which are the costs and benefits, [15]. The primary objective of a CBA is to develop a standardized model so that it is possible to assess the implications of certain actions. Hence, this analysis follows a pros and cons method of a choice. It is essential that a model can predict all the effects on the economy when carrying out a project, to be able to assess several points of view and what their repercussions might be. One way of calculating the total effect in terms of impact is to make a comparison between the economy with and without the development of the project in question, [11]. At the time of an economic evaluation, the most theoretically complete method for an evaluation followed by decision making in a project is a CBA. The main difference between CBA and other possible methods is the assignment of monetary values to both inputs (costs) and outputs (benefits). This makes it possible to compare the monetary ROI in one sector with the ROI in other economic areas, [11]; [17].
Methods used as complements in CBA, such as ROI, are very useful tools to support and make decisions, particularly when it comes to capital expenditure, [14]. This is a cost-benefit analytical method driven by monetary value. It is also a great instrument for decisions in projects namely when allocating resources that are scarce. ROI is calculated in the following general way: ROI = (net benefits/net costs) × 100%. The conclusion that can be drawn from the ROI calculation, is whether a given project is beneficial, ROI is a positive figure.
Another important indicator to measure a project's viability, used in CBA is the PP. The PP is defined to be a way of evaluating investment prospects determining how long it will take for the forecast cash inflows from an investment to repay the original cost, [3]; [14]. The general formula to obtain this indicator is: PP = Net investment/Average annual operating cash flow.

[8] CBA - Cost-Benefit Analysis

4. Methodology

The methodology pursued in this work is represented in figure 2, consisting in seven steps.

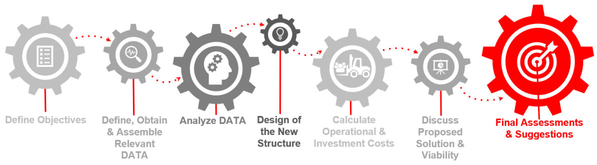

Figure 2: Methodology to Develop the Design of a Structure in a Warehouse

4.1. Data Collection

A study was carried out for the year 2021, to understand which categories are effectively stored in the area 701 solo area. This being said, ten categories were theoretically stored in this area of the warehouse. Afterwards, it was necessary to determine which of these categories actually pass through this area. This allows to associate quantities with items in categories. It was found that there were many of these categories that due to a series of reasons, their products had not been effectively stored in the area under study. The categories that will be studied and analyzed in depth from this point on are six: 5102 - Máquinas da Roupa; 5103 - Máquinas da Loiça; 5104 - Fogões; 5105 - Frio; 5106 - Encastre e 5108 - Ar Condicionado. The final range of categories under study represent over 99% of the products stored in this area.

4.2. Analysis

A first analysis was previously made, calculating the standard deviation values within each category, consolidating heights and products stacking factor but no conclusion was reached due to the high values variations. A second analysis began with the setting up a simulator to serve as a base analysis to determine which might be the optimal height to built the platform considering product ranges and necessities. The first step was to built the entire data base, using the 2021 stock relatively to 701 solo area. It was developed to be considered in simulator metrics, five safety factors (see upper left corner, figure 3), when considering the useful heights underneath and above the platform. The ceiling height has a fixed value of 12m, however for further calculations it will be considered the higher point of the ceiling, 11m (due to construction beams). The simulator interacts with the user through the INPUT value, that is an inserted height without any coefficient considerations. It was also created a warning message, if the user inserts an INPUT value (see middle of left side, figure 3) that does not leave the safety margin explained previously for this factor, saying that the value entered has to be higher or lower to be able to do the handling in the area. The user also has the option to simulate space considering all categories and subcategories or select which one through the click in two slicers used (see right side of the safety coefficients, figure 3). What initiates the entire generation of simulator outputs is the refresh button (see middle of left side, figure 3). The refresh button is the start of the entire simulation, allowing all values to be generated and calculated. This distinction of outputs (see right upper corner, figure 3) is important, because evaluating space in terms of units can sometimes be unreliable, since it depends a lot on the type of equipment to store in that particular time. That is, storing more units is not proportionally related to the increase in space, because the warehouse may be storing smaller items or even with higher stacking factors coming from the factory. In the output graphs, visualize figure 3, it is presented green bars and red bars, for average percentages of free space and occupied space each month, respectively. Both variables evaluate relative to the stock that was actually stored throughout the year 2021, with the variant of the desired structure, the platform. The user can understand, for a given stored quantity, how it would be distributed with the implementation of this new project, and what gains in terms of space it will provide.

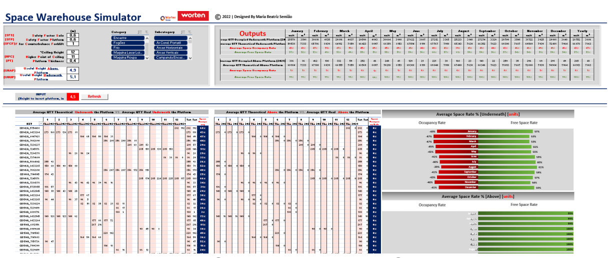

Figure 3: Space Warehouse Simulator

The construction of the simulator database was the most complex and time consuming portion of the work, due to the creation of formulas and mathematical models that allowed to obtain and meet the objectives of the simulator. The database created in *Excel*, using the program's various functionalities, presenting itself with 61 columns and 286 203 rows of data. The developed simulator contemplates the square meters of the available locations, contemplating two main spacial variables, both the heights of the products, and occupied space by each stack. The key column that allows the identification, follows the idea Location_ItemName, see left side, figure 3.

Scenarios Simulation

Based on the designed simulator, ten simulations were run to achieve an optimal outcome for the height at which the platform should be built. It is important to emphasize that determining the optimal platform height involves several non-mathematical considerations, which need to be taken into account, relative to the operation and all the logistics of the warehouse. The outputs of the simulator, in terms of the table and respective graphs explained previously, will only be shown for the optimal solution of the case under study. All simulations were ran without any filter in terms of categories and subcategories, because it is of interest to be able to store all the types of products that are already stored today, and that were stored in the past, by the time of the 2021 readings. The resume output of the simulated scenarios can be found in figure 4.

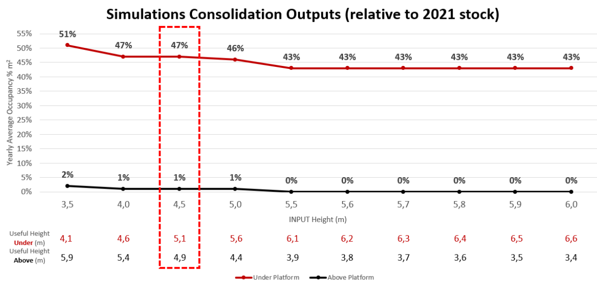

Figure 4: Executed Simulations

It was then determined, looking at all ten simulations performed, graph 4, that the optimum height would be with an INPUT value at 4.5 m, resulting in a useful height below the platform of 5.1 m and 4.9 m over. Observing the output of all simulations, this INPUT value was decided as optimal, because for the operation's working and to be able to satisfy the needs of fluctuations in the dimensions of the large domestics that are stored in this area, it makes possible to store the same typologies both on top and on the bottom of the structure, having as a primary guide, the verification of the existence of sales coverage stock for a time gap of

2 weeks. This height both below and above the platform also introduce further advantages, such as over sizing in view of storing the tallest product ever stored, which is an American Refrigerator with a height of 2.5 m with a stacking factor of 2 units. Using the calculated useful dimensions of heights on both floors of the platform, it is possible to meet this need, as the maximum stack height will be 5 m. A height of 5.1 m is available at the bottom and 4.9 m at the top, even though the latter is less than 5 m, these calculated working heights include various safety factors and margins that continued to be matched and applied for the most part, even with the extra 0.1 m required.
Evaluating the simulation scenario for the optimal height selecting independently of each category, it is possible to see that in all cases except for the Ar Condicionado category, the upper part of the platform remains mostly free and unoccupied. However, these products are not a concern, because they are a seasonal product that need coverage stock only during some months of the year. This fact allows us to realize that by building this structure the available space would double in most months of the year, for the same range of products. Most of the products that will be placed above the platform in all the simulated scenarios, is due to the reason that the maximum stacking factor for some products it is not allowed to happen because of the platform itself. Underneath the structure, all categories, with the exception of Ar Condicionado and Frio always have an average occupation of space in terms of square meters around 40% to 50%. These percentages match the current space efficiency. This low percentage is justified by the low efficiency of this type of system in lock stacking, taking into account the needs of aisles and spacing for the handling of products, and also not forgetting the fluctuations of SKUs entering the warehouse. This always maintaining a dedicated storage policy, placing only one SKU in each location.

4.3. Design of the New Structure

New Structure´s Operational Flows

Taking the journey of a big-sized appliance when it enters the company's warehouse, regarding a more operational and process point of view. In a first phase, the truck pulls up at the destined dock, and the unloading of the products takes place. The items are placed in the receiving lines to undergo the checking process of the merchandise, and in some cases also the quality control team to ensure that there is no damaged products. This flow of entries will be exactly the same as the system as is. To recall the process. In a second phase, with the products already checked, they wait on the lines to be stored into the available locations. This is where variations from the current system come into play. The objective is that when the platform exists, and is used to store the products, they suffer the least number of movements possible, both for reasons of possible damages, and also concerning the productivity of the processes. The WMS[9] will continue to apply a random and dedicated storage policy, i.e., only one SKU (one reference) is stored per lane. Therefore, this second phase will be divided into two stages. A first stage, in which the products that are in the lanes are replenished from the bottom of the platform in order to immediately replenish the previous day's locations that are empty or with lower occupancy rates and have corresponding SKUs to fill them, having always a coverage stock for 2 weeks. In this part of the process, the most important factor to be carried out in every put away activity, is the verification in WMS system, that every SKU has stock coverage for 2 weeks. The fulfillment of this requirement automatically reduces the number of movements in terms of down and up, as intended. Once all the space underneath the platform is full, or as full as possible for the products to be replenished, the rest are stocked at the top of the platform. Here in this second step two new movements are introduced. One movement for lifting the products and another, in which a counterbalance forklift with clamps is permanently on top of the platform, which organize the products in the right locations, performing the put away activity above the platform. This equipment will always stay on top of the platform. In a third phase, in terms of replenishment, this is done with preference to the consolidation of products and compacting locations coming from the reception. However, it may be necessary at some point, particularly at peak times when product rotation is even higher, that an extra step of lowering products from the platform to the ground is needed in order to meet the daily picking needs. In a fourth phase, the phase in which the picking of products is carried out for subsequent shipping, this is always done only and exclusively from the bottom of the platform. Meaning that there are only active locations on the solo area. On top of the platform the locations are considered as reserves. Even if the desired product is only at the top of the structure, an order will then be executed in the PDT for the product to be lowered, and then the picking is executed. This process ends with placing the products in the shipping lines. In a fifth and a last stage, the shipping operation is then performed.
The platform will have in both inbound and outbound sides, stairs that will allow personnel access to the platform. It will also be implemented a handrail around the platforms perimeter to ensure

[9] Warehouse Management System

security. As well as three gates, called "endless", two on the reception side and one on the dispatch side in order to speed up the movements and make the whole process safer. A minimum of two operators will be required for bottleneck-free operation on top of the platform.

4.4. Operational and Investment Costs

System As Is

The only cost center directly linked to the current system, and which has undergone a large increase in recent times, is the space rented from a company that provides 3PL[10] services, in order to meet the space needs of the products to be stored, to fulfill and feed Worten daily's operations.

In a detail analysis, it was verified that in the years 2020, 2021 and in the first months of 2022 the trend was always increasing. Making a direct comparison between 2021 and 2020, in the total square meters rented in both years, there was an overall growth of 33% in the space spent for storage of big-sized appliances. However, this need is ever-increasing, and the permanently growing figures since the beginning of 2022, lead to records in the company, reaching rented values such as 13 900 m^2 in the month of March. In the first 4 months of the year, 2022, about 65% of all rented space from the previous year has already been rented. Therefore, growth percentages are marked comparing the year 2022 with 2021, of 80%, 94%, 138%, and 363% for the months of January through April, respectively.

As expected, as the m^2 rented and necessities increases, the costs follow the exact same trend. There are some exceptions that this trend may not occur, because this rental cost does not only contemplate storage values, but also handling, transportation either from the port or from the central operations warehouse, and also some extras that may be needed in a given month, such as arrangement or rearrangement of locations, labeling, conferences/audits, among others.

The system described with all the steps of this alternative flow necessity, causes heavy costs for the company, with a successively increasing trend as the business volumes rise, adding a major advantage which is the decentralization of operations, thus also incurring in the increasing cost in terms of necessary transfers, making the profit (on a given product) much lower. It is still important to highlight the damage aspect, because as more movements the product experiences, the greater the probability of suffering some kind of damage that results in its impossibility to be sold, without any return of that value.

[10]Third Party Logistics

Design To Be

After involving several entities inside and outside the company, namely suppliers, the budget for the construction of the platform and all the costs that this entails was obtained including labor, materials, raw materials, equipment rental, project drawings, inspections and others. The investment required to implement this project is 1,591,739.16 €. However, for ROI and PP calculations, a 20% up was considered, due to the foreseeing increases.

The values obtained for the PP and ROI are in table presented 1, with a sensitivity analysis for three different scenarios: 5%, 10% and 15% increase in costs for 2022-2023 and 2023-2024. For the remaining year 2022, the reasoning used to calculate the trend for the remaining months of the year, May through December, was an average of the percentages of growth in the first 4 months of the year over last year. This average had a value of 58%.

Table 1: PP and ROI Evolution if the companies growth is 5%, 10% and 15%

Cost of Investment (2 080 774.22€)		
Growth (yoy)	**PP (years)**	**ROI (5 years)**
5%	2.52	98%
10%	2.43	106%
15%	2.34	113%

5. Results Discussion

It is now important to perform a general analysis of results, namely regarding the feasibility of the project, its implementation and possible limitations. It was possible to observe, in table 1 that for any growth percentage considered, the investment is highly profitable, since all the values for the PP are lower than 2.6 years, and also results concerning ROI are higher or almost 100%. This means that evaluating the investment in the long term, 5 years of analysis, considering a growth of only 5%, the implementation of the structure pays itself in 2.52 years, and at the end of 5 years besides this value having already been paid in full, there is still a gain of 98%. It is still possible to conclude that if the project had advanced in the year 2020, today, there would only be 1 months left for it to be paid in full (June 2022). PP allows the company to understand how long it would take to pay off the investment, taking into account the savings resulting from the implementation of this project. The ROI represents the annual percentage within the PP that will give that return on investment. However, it is important to realize that not all projects and investments have a specific horizon, so the value obtained in the PP, must be nested within the larger context of that time horizon. The last indicator, however, does not contemplate the time value of money. Additionally, not all cash flows are considered. Nevertheless, PP is a great preliminary screening tool for projects that do not satisfy payback criteria and not moving forward due to their infeasibility. When approaching ROI indicator, the most significant benefit of using this indicator is that it is a simple mathematical formula to compute and comprehend. One of the drawbacks of ROI is that it does not account for an asset's holding term.

These two indicators are very important in this type of validation considering monetary gains, however it is also important to make all trade-offs, even those that are not directly reflected in costs reduction for the company, but can provide clear advantages for a more sustained and centralized operation.

After planning the structure, several analyses and ten simulations were performed on the previous mentioned simulator, was concluded that the most advantageous height for the space would be for the platform to have an INPUT value of 4.5 m. Arriving at this conclusion and after all the structural plan carried out, as well as the financial segment, in terms of budget and costs that this investment entails, the new structure will allow to double the currently available storage space from 8513.39 m^2 to 17026.78 m^2. Both values are relative to useful space, not counting the m^2 needed for circulation aisles, which will follow the same current trend, counting around 25% of the space. In April of 2022, the company had the need to rent around 13900 m^2. This value compared with the amount of square meters available in the central operations warehouse, has an impact of over 1.63 times the amount of space we have available today. Evaluating this same month, with the investment in the platform structure, this external rental need would decrease, needing to rent only 5386.61 m^2. Which allows us to conclude that although the platform can mitigate the need for outsourcing space, it will not eliminate it entirely.

Therefore, this work suggests to Worten, the segmentation of the supply chain and flow operation considered, always bearing in mind the long-term horizon, and the entire growth trend that is noted year after year. If Worten opts for a permanent solution and that will keep the operational needs probably fulfilled for the next decade, this solution will have to consider a separation of small domestic 708 and big-sized appliances 701 flows regarding warehouses. Carrying out a procurement of a large space near the current warehouse and implement the platform project while there is no operations in that area, transferring after all the products. This decision will allow the company to stop renting any external space, keeping its operation totally centralized in one space, substantially reducing transport and handling costs. With this type of specific focus of the space, the operators working in each one could be fully trained, allowing to have qualified people, reducing the probability of breakage and damage of products, increasing the productivity and efficiency of the entire operations. This suggestion comes from the fact that the solution developed cannot yet meet 100% of the company's needs in the current space. It is very important in the near future that the company seeks long-term and somehow permanent solutions in order to stabilize its own supply chain. Evaluating in practical terms the construction of this platform today, with an operation running 16h/day, 7days/week, it will be very complex and to some extent dangerous and enormous effort to keep the warehouse operations without disruption. Added to this the fact that the space must be emptied, even in stages, before the structure can be put in place. To this must be added the fact that several construction machines have to be on site to support the work, and many outside personnel, endangering the goods inside the warehouse.

The operational arguments that will be mentioned next further support the suggestion of a segmentation of the supply chain, targeting the big-sized appliances segment in a second warehouse. Currently, the number of containers to be received is increasing, often unexpected, which requires a lot of effort from the entire operation to be able to align its receptions, managing the internal and external space (adding the difficulty that in the external side the system in terms of *software* used is not the same as the main warehouse, since it is not owned by Worten). These often unexpected peaks lead to very high costs, from containers that need to stay longer in port due to lack of reception and space, to the need for temporary hires to be able to meet the unloading demands in the various warehouses (central and external), passing through the numerous transfers between spaces, until orders can be prepared in the only place where shipping is done, the central warehouse, for delivery to the final destination. All these extra costs, with the recent war in Europe and the grow of the minimum wage in Portugal, has suffered substantial increases. As time has passed the company has been looking for to expand the range of products offered to the customer, as well as entering new businesses.

Addressing the issue of the layout of the current system, when building the platform the space will have the same segmentation in terms of locations both below and in the replication of the space above. This layout was carefully studied in order to make maximum use of space. The various dimensions presented of the locations were also studied to be able to respond efficiently and effectively to stock entries in the warehouse and the SKUs required.

In several product models, namely refrigerators, there is a stacking factor that comes from the manufacturer, but nevertheless, there is a note on the packaging that indicates the possibility of stacking 1 more, in case of the same model. However, this is not the safest situation, because the stacking factor must always be considered. The platform would help not letting these cases happen because the available height would never allow it, always going over the platform. Here we are securing the products in terms of storage breaks in the locations. However, regarding the put away and replenishment of the items, this could insert here an increased factor of the drop in the placement of the products either from below or from above the platform. This is one of the factors that has to be considered in the investment trade-off.

The introduction of the platform in the operation, even with two new hires of employees to work on top of the platform, will overload the operation, adding more effort, because both the reception needs to respond to the entries, as well as the supply team of the 701 solo area, has to be able to move along with this increase, and the ascent and descent of products it will be a more delicate activity that requires full attention from the employee and also experience in handling the equipment.

The number of compactations will have to be a priority activity, further increasing the effort load, in order to always ensure that the space is occupied at its maximum efficiency, both below and above the platform. Underneath the structure the criticality is even greater in order to ensure stock coverage of 2 weeks.

Lastly, it is convenient to mention the limitations of the simulator built as a tool to analyze the project outputs. The limitations pass through essentially by three points. The first limitation is related to the simulator database depending on readings taken through a *script* that is programmed to run every day, however, sometimes some complications occur with this computational run base, which causes some days when it does not run and no data is obtained. The present simulator, based on readings in 2021, ran 360 days due to system failures. It would be important to ensure this constant data feed, so that daily and concise readings could be guaranteed, although the days on which results were not obtained were few. The second limitation of the system is precisely because the simulator is fed at the moment by the stock stored in the warehouse in 2021 in the area under study, which makes this a tool for only evaluating the passing stored products, not including new SKUs, or ranges that may already be in storage today. The third and last limitation of the simulator built is precisely because it is not a daily management tool, since it only incorporates in its database the stock stored last year, however this was not a master thesis objective. Thereby, the last two limitations presented mean that we are always looking to the past and not to the present. However, it should also be noted that the differences in terms of spatial dimensions of the products will not diverge in such a way being inconsistent with the simulator data. However, how to combat these limitations will be the basis for suggested future work, a continuation of this paper.

6. Conclusions

Moving forward to a more conclusive part of this paper, it is possible to see that after all the points presented, the relative area in the warehouse for big-sized appliances is not enough since the previous year, 2021, following the same trend this year, 2022, and with a growth curve expected due to the coverage of ranges and increasing diversity of products sold by the Worten, which is one of the milestones that has been reached in recent times by the company.

Therefore, with this paper, an entire case study of the company in question was carried out, detailing all operations relevant to the warehouse, as well as explaining the challenge proposed by the company and its objectives. Next, a research, on what types of storage are most commonly used for larger products. After studying several options and evaluating several trade-offs, it was decided to pursue with the platform solution. From this point on, it was defined a methodology, starting with a complete analysis of the warehouse data. The work then evolved with the development of a working tool, a simulator, to be the basis for supporting the determination of what would be the optimal height of the platform. It was then supported with the execution of ten simulations and the analysis of multiple trade-offs that the optimal height of INPUT of the simulator would be 4.5 m. However, the best decision to be taken would be to build the platform, requiring a substantial initial investment, but paying itself in less than 2.6 years. Due to several operational constraints and the need to stop part of the warehouse operations, another solution was suggested with a longer time horizon, which is to acquire a new warehouse, segmenting the supply chain, so that there is a warehouse 100% dedicated to small and big-sized appliances. In this second warehouse, after acquiring the space, studies would be carried out to implement the suggested platform, and then shift the operation of this type of products to the new area. With this conclusion implemented, Worten would no longer need to outsource space, substantially reducing its costs and depending only on itself for operational functioning.

Regarding forthcoming work, looking to the future, and what it can be done today to improve tomorrow. As of today, it only incorporates data from 2021, always taking into account the stock that was actually stored, and the present layout of the area under study, with the construction of the platform. However, this simulator could be adapted for the daily management of the warehouse. In other words, feeding the database with the deliveries planned for the day or the week, and from there always being able to monitor and optimize the space, also understanding what the percentages of efficiency are. If Worten select the suggestion previously made to expand operations to a second specially designed warehouse for big-size appliances, through the construction of the structure idealized in this paper, serving as a base model.

References

[1] Ohra mezzanine floors. https://www.ohra.ie/products/storage-platform. Accessed 11-April-2022.

[2] Plataformas. https://www.mecalux.pt/estantes-outros-sistemas/plataformas. Accessed 11-April-2022.

[3] C. V. Asche, M. Kim, A. Brown, A. Golden, T. A. Laack, J. Rosario, C. Strother, V. Y. Totten, and Y. Okuda. Communicating value in simulation: cost–benefit analysis and return on investment. *Academic Emergency Medicine*, 25(2):230–237, 2018.

[4] P. Baker and M. Canessa. Warehouse design: A structured approach. *European journal of operational research*, 193(2):425–436, 2009.

[5] J. Banks. *Handbook of simulation: principles, methodology, advances, applications, and practice*. John Wiley & Sons, 1998.

[6] S. BARTHOLDI, John J. ; T. HACKMAN. Warehouse distribution science. https://www.warehouse-science.com/book/editions/wh-sci-0.98.1.pdf.

[7] J. S. Carson. Introduction to modeling and simulation. In *Proceedings of the Winter Simulation Conference, 2005.*, pages 8–pp. IEEE, 2005.

[8] L. Chwif, M. R. P. Barretto, and R. J. Paul. On simulation model complexity. In *2000 winter simulation conference proceedings (Cat. No. 00CH37165)*, volume 1, pages 449–455. IEEE, 2000.

[9] G. Cormier and E. A. Gunn. A review of warehouse models. *European journal of operational research*, 58(1):3–13, 1992.

[10] S. Derhami, J. S. Smith, and K. R. Gue. Optimising space utilisation in block stacking warehouses. *International Journal of Production Research*, 55(21):6436–6452, 2017.

[11] J. Drèze and N. Stern. The theory of cost-benefit analysis. In *Handbook of public economics*, volume 2, pages 909–989. Elsevier, 1987.

[12] J. P. Gagliardi, J. Renaud, and A. Ruiz. A simulation model to improve warehouse operations. In *2007 Winter Simulation Conference*, pages 2012–2018. IEEE, 2007.

[13] A. M. Law, W. D. Kelton, and W. D. Kelton. *Simulation modeling and analysis*, volume 3. McGraw-Hill New York, 2000.

[14] M. Linn. Cost-benefit analysis: a primer. *The Bottom Line*, 2010.

[15] T. F. Nas. *Cost-benefit analysis: Theory and application*. Lexington Books, 2016.

[16] M. Parlar, D. Perry, and W. Stadje. Fifo versus lifo issuing policies for stochastic perishable inventory systems. *Methodology and Computing in Applied Probability*, 13(2):405–417, 2011.

[17] R. Robinson. Cost-benefit analysis. *British Medical Journal*, 307(6909):924–926, 1993.

[18] S. Robinson. Conceptual modelling for simulation part i: definition and requirements. *Journal of the operational research society*, 59(3):278–290, 2008.

[19] S. Robinson. Conceptual modeling for simulation. In *2013 Winter Simulations Conference (WSC)*, pages 377–388. IEEE, 2013.

[20] M. D. Rossetti. *Simulation modeling and Arena*. John Wiley & Sons, 2015.

[21] A. Rushton, P. Croucher, and P. Baker. *The handbook of logistics and distribution management: Understanding the supply chain*. Kogan Page Publishers, 2014.

[22] R. Vujanac, N. Miloradovic, and S. Vulovic. Dynamic storage systems. *Annals of the Faculty of Engineering Hunedoara*, 14(1):79, 2016.