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

The Case Study of Worten

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Para o meu priminho Martim, que todos os dias é um lutador...

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Abstract

Nowadays, the retail sector faces daily challenges and constant change. In order to keep up with market growth and be a top competitor, it is sometimes necessary to stay one step ahead in terms of competitive advantage. One of the vital points in a supply network is the warehouses, which are responsible for receiving, picking, storing, preparing, and sending the desired products in the right measures, respecting the commitment service levels. Storage needs have increased. It is therefore vital 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. The present Master's Thesis in Industrial Engineering and Management aims to study and provide a design solution for the improvement of a storage area intended for big-sized appliances at Worten. The design should aim to be as efficient as possible, achieving the best compromise between storage and the respective investment. To achieve this goals, constant and daily visits were made to the company's operation, along with suppliers capable of bringing the idealized structure to life, managing to satisfy all Worten needs. A tool was then designed, consisting of a space warehouse simulator, which will serve as support for the effective operation of the suggested structure.

Keywords

Warehouse; Block-staking; Storage Design; Storage sizing; Simulator; Cost-benefit Analysis.

Resumo

Hoje em dia, o sector retalhista enfrenta desafios diários e mudanças constantes. Para acompanhar o crescimento do mercado e ser um concorrente líder, é por vezes necessário estar um passo à frente em termos de vantagem competitiva. Assim vários pequenos retalhistas que não conseguiram acompanhar este crescimento tiveram de abandonar o mercado, deixando-o controlado por um número muito reduzido de organizações. Estas controlam mutuamente os preços diários, sendo necessário apostar na única coisa que os pode diferenciar, o consumidor. Satisfazer a procura do consumidor é um desafio e precisa de ser garantido para se atingir o sucesso. Um dos pontos vitais de uma cadeia de abastecimento são os armazéns, estes responsáveis pela recepção ao envio dos produtos desejados nas medidas certas, respeitando os níveis de serviço. As necessidades de armazenamento têm aumentado. Por conseguinte, é vital redesenhar a disposição de certas áreas críticas, a fim de poder armazenar volumes maiores de forma mais eficiente, tornando ao mesmo tempo a operação capaz. A presente Dissertação visa estudar e fornecer uma solução de design para a melhoria de uma área de armazenamento destinada a grandes domésticos na Worten. O design deve ter como objectivo ser o mais eficiente possível, conseguindo o melhor compromisso entre o armazenamento e o respectivo investimento. Para este fim foram realizadas visitas constantes e diárias à operação da empresa, conseguindo satisfazer todas as necessidades da Worten. Foi então desenhada uma ferramenta que consiste num simulador de espaço, que servirá de apoio para a operacionalização eficaz da estrutura proposta.

Palavras Chave

Armazém; Armazenamento em Blocos Empilhados; Design de Armazenamento; Dimensionamento de Armazenamento; Simulador; Análise Custo-benefício.

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Acronyms

1PL	First-Party Logistics
3PL	Third-Party Logistics
AH	Average Height
APR	Adjustable Pallet Racking
ASH	Average Stacking Factor
ASN	Advanced Shipping Notice
B2B	Business to Business
B2C	Business to Consumer
BSS	Block Stacking System
CBA	Cost-Benefit Analysis
COI	Cybe-Per-Order Index
CQTY	Correspondent Quantity
DIN	Drive-in Racks
e-commerce	Electronic commerce
FIFO	First-In, First-Out
HD	Home Deliveries
HPC	Higher Point of Ceiling
iLPN	inbound License Plate Number
KPI	Key Performance Indicator
LIFO	Last-In, First-Out
LS	Logistics Service
MF	Supplier Brand (comes from the Portuguese words ”Marca Fornecedor”)
MP	White Brand (comes from the Portuguese words ”Marca Própria”)
oLPN	outbound License Plate Number
PBL	Pick by Line
PBS	Pick by Store
PDT	Portable Digital Terminal

PH	Product Height
PPileH	Product Pile Height
PP	Payback Period
PTL	Put to Light
PTS	Put to Store
PTZ	Put to Zone
PT	Platform Thickness
QC	Quality Control
RFID	Radio-Frequency IDentification
RF	Radio Frequency
ROI	Return On Investment
SCED	Complementary Service of Home Deliveries
SC	Supply Chain
SFCF	Safety Factor Counterbalance Forklift
SFP	Safety Factor Platform
SFS	Safety Factor Solo
SH	Sacking Factor
SKU	Stock Keeping Unit
SM	Slow Mover
SQL	Structured Query Language
STDEV	Standard Deviation
UHAP	Useful Hight Above Platform
UHUP	Useful Hight Underneath Platform
UTRAD	Repair of Damaged Products for further outlet selling (comes from the Portuguese words ”Unidade de Tratamento e Recondicionamento de Artigos Depreciados”)
WMS	Warehouse Management System

1. Introduction

This chapter is a brief introduction that provides an overview of the document, framework, and an explanation regarding the problems´ objectives, following a summary of the approach established in this dissertation.

1.1 Problem Background

Nowadays, after the world has faced a pandemic crisis, adding the recent war in Europe, some paradigms have changed, others have only been accentuated, requiring constant and continuous adaptations of the past by supply chains around the world, including all operational nodes and key links that are part of this network. All this scenario, and with the increase of periods of confinement, consumers have embraced alternative platforms en mass, making e-platforms grow exponentially and adding even more value to an omni-channel grid, [12]. With this unbridled growth, constant disruptions, the supply networks went through a pressure never seen before. Warehouses, which previously represented high costs and low performance, have become a central supply point, serving as a direct link to the customer at a time when most sectors had to keep their stores closed, [13]. Every day new demands arrived, and with them more demanding consumers. From one moment to the next, space became a critical factor. From the upstream flow, unexpected quantities arrived on unexpected days, forcing the warehouses to exercise an extra effort to keep up with the new conveniences. Therefore, new performance indicator targets had to be met, such as increasing the productivity of the systems, as well as their accuracy, while reducing inventory costs and providing the best customer service in order to be able to compete in the market.
Worten, actively present in the Portuguese and Spanish markets, leader of the consumer electronics and entertainment retail sector in Portugal, is the company that will be studied in this dissertation. Undoubtedly distinguished for offering its customers the best value for money proposition in the electronics market. In order to do justice to its value, always presenting the lowest price, it needs a highly efficient storage structure in order to reduce operational costs. Space is one of the most critical factors that influence all flows: input, storage, operational, and dispatch. Without space, a company cannot meet the demand of its consumers and from this point it snowballs, forming a tremendous bottleneck in the chain. The present dissertation deals with the design of a highly efficient structure to store as many big-sized appliances as possible, achieving a highly effective cost-benefit ratio, in the central warehouse of the Worten supply chain.

1.2 Objectives

The primary objective of the present dissertation is to reach a possible solution that can be adopted by the company, Worten, for a substantial improvement of space usage and organization, in order to meet the current needs of the company and the business. For the presented structure/system, provide what trade-offs are in question, as well as the financial viability of the project in question. In order to achieve these goals, the path to be followed was broken down into seven smaller support objectives. The first one consists of presenting and characterizing the problem at hand concerning the case study; The second get a solid theoretical background in the subject, carrying out a bibliographical review; The third one is to perform a study the current warehouse capacity, from inbound, through storage, to outbound; The fourth objective is to define entirely the solution considered; The fifth one is to build a tool that will serve as a study base for determining the structural objectives; The sixth smaller objective passes through the determination of the possible budget for the solution; At last, the seventh smaller objective is to evaluate projects viability.

1.3 Dissertation Structure

The master thesis is comprehended into 7 major chapters:

- **Chapter 1 - Introduction**: The first chapter is intended as an explanation to the reader of the problem to be addressed in this dissertation, including the driving force for its realization. Next, thesis´ structure will be explained briefly.
- **Chapter 2 - Case Study**: The second chapter consists essentially of the case study, a presentation is made of the company where the dissertation is being developed, as well as its position in the Portuguese market. It is also inserted the problem in the business entrepreneurial context, and which are its main drivers.
- **Chapter 3 - Literature Review**: This chapter is based on scientific research of what is similar in the market, and what studies have been carried out concerning the topic in question.
- **Chapter 4 - Methodology, DATA Collection and Analysis**: The fourth chapter of this master thesis consists in simple explanation of the thesis methodology, as well as the representation and study of all collected data from Worten cloud.
- **Chapter 5 - Design Development**: The solution that should be adopted is presented. The new structure is then designed and explained both in operational and functional terms. Next, the entire development of the base tool of this dissertation, a space warehouse simulator, is fully explained. Finally, the costs of both the current system and the scenario to be are addressed.
- **Chapter 6 - Results Discussion**: The penultimate chapter of the master thesis discusses the feasibility of the solution in financial and operational aspects. A final suggestion for Worten to pursue is made, based on the design tool - Space Warehouse Simulator.
- **Chapter 7 - Conclusions and Future Work**: In the seventh and final chapter, a conclusion is made of the various key points through out the dissertation in a macro way. A section is also dedicated to the reflection of possible points for further development of this master thesis with added value for the company, Worten.

2. Case Study

In this section of the project, it will be presented an overview of how Worten is inserted into the business of Sonae corporate group, pinpointing its relevance into the Portuguese benchmark, starting with main thinking strategies and supply chain growth, passing through the warehouse operations itself. Finally, it will be contextualized in detail the main drivers that took Worten to identify the problem and propose the challenge at hand.

2.1 Sonae

Sonae is a multinational company founded in Maia, Portugal by the entrepreneur and banker Afonso Pinto de Magalhães back in 1959. The name Sonae comes from its routes after the **So**ciedade **Na**cional de **E**stratificados, where the business group started as a small to medium-size business company operating in the industry of processed wood, specialized in the production of ornamental laminated panels for the first decades of its existence.

From its origin to the present day, Sonae has grown exponentially over the years, owning eight sub holdings: Sonae MC, Sonae Fashion, Worten, ISRG, Sonae FS, Sonae IM, Sonae Sierra, NOS, presenting a spread portfolio of businesses in retail, financial services, technology, shopping centers, and telecommunications, comprising more than 66 brands. Sonae has also other related companies such as: Sonae Capital, Sonae Indústria, and Efanor that incorporate other areas of expertise like hospitality, fitness, energy, refrigeration, AVAC, and more. The company's core is to create value in several geographies, nowadays based in 90 countries dispersed over the 5 continents, with a solid culture and a high capacity to innovate and execute, bringing the benefits of progress to a growing number of people (Sonae, 2021). In 2020, it was conducted a study by McKinsey, INSEAD, Nova SBE, and Euronest that has stood out Sonae as the leading company in Portugal as far as encouraging gender equality is concerned. Today´s Sonae slogan is *improving life*. Recent data of March of 2021, shows from a statutory point of view, Sonae's consolidated turnover grew 6.1% yoy[1] to 6,827 M€, mostly driven by the positive contributions of Sonae MC and Worten. The next part of this chapter will be regarding our business segment that will be entirely dedicated to Worten.

2.2 Worten

Worten is a retail company specializing in consumer electronics and entertainment that belongs to Sonae. Founded in 1996 and is positioned today in the top 3 players in the Iberian Peninsula and the Canary Islands. Within the Sonae universe, Worten is the second biggest contributor to the continued increase of the group´s turnover. The company's slogan is *"Worten Sempre"*, and it describes itself

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[1] Year-over-year

as *“a digital company, with physical stores and a human touch”*, (Felipe Ferreira, 24 June 2020).

At the present day, Worten has one central warehouse and currently 155 physical stores, in Portugal, another central warehouse near Madrid that fulfills one store in Spain, and finally another central warehouse in the Canary Islands. Physical stores are available in two typologies: superstores, with up to 500 m^2 of available selling space, placed in shopping galleries in Continente Modelo hypermarkets and megastores, with around 2000 m^2 set in shopping centers. Nowadays, Worten has some brands of its own, considered White Brand (MP), such as Becken, Mitsaim, Kunft, Goodis, KUBO, Nplay, and Matizcore that have guaranteed year after year the certification of the quality management system. In the first half of 2021, Worten released its latest results exhibiting a turnover of 1,161 M€, 17% of Sonae´s world, an improvement from the previous year of plus 7%, with online accounting for more than 10% of sales.

Throughout the years, Worten has aimed to provide the widest possible range of items at the best market price, keeping always in mind the *Kaizen policy* of continuous improvement. The online market *worten.pt* was launched in 2001, opening a whole new sales universe, in which it became possible to reach all customers in the comfort of their homes. In 2004, it was founded Worten Mobile, which main focus is on mobile devices, accessories plus communication packages, and in 2013 it was created Worten Resolve, a brand that gives support to software updates and equipment repairs regardless of the place of purchase, brand, or model and allows customers to follow their repair in real time. Today exists 37 physical stores of both types.

In 2016, as times have changed, it became more important every day to create a unified user experience. The company understood that today’s consumers use a wide variety of channels to interact with businesses, and often do so simultaneously moving towards an omnichannel. Always to satisfy the consumer, the marketplace was created in 2018, an Electronic commerce (e-commerce) platform that allows a seller to use the official Worten website to sell their products directly to the customer. This initiative allowed the opening of a new sales channel that had a great impact on the volume of items sold, representing in 2019 about 20% of the total sales of Worten’s website. To make this project grow and inject new ideas, Worten is developing a fulfillment project, which is available since October 2021, that will additionally allow the seller to choose if they want Worten to store the items, sell them on its platform through the marketplace and, when sold, pack and ship them to the final consumer. The transport of these orders will be inserted in the current shipping network, increasing the outbound volume, and decreasing the shipping costs per item. This new possibility allows Worten to be a Third-Party Logistics (3PL) and not only a First-Party Logistics (1PL), as it currently is.

A few years ago, in 2019, Worten also implemented the possibility of storing third-party goods in the warehouse, achieving here a mutual benefit for both parties. This is a 1PL service, called Logistics Service (LS), and presents a source of income in the warehouse related to storage.

2.3 Supply Chain Network

From the creation of the Worten brand until today, it is possible to observe a growing and progressive evolution, aiming to accomplish new challenges and always going hand in hand with the gradual needs of its consumers. Thus, today, a series of improvements are already available that make the purchase of a product easier and more efficient. In the early days of Worten, the Supply Chain (SC) was characterized by being linear, as it can be observed in figure A.1, in Appendix section A, with only exchanges of flows from suppliers to the warehouse, then from the warehouse to the stores, being the stores the only and final contact to the final customer. Here, there was little contact between warehouse-consumer and even supplier-consumer. Thus, the need was felt to make this system more interactive, complex, and able to keep up with the technological evolution of times and the growing needs of society. A SC was then created with a dynamic interconnection, presented in figure 2.1, with the appearance of the online universe that was unknown until that moment. The current network configuration is completely integrated, focusing on an omni-channel operation centred on the consumer's shopping experience that increasingly aims to bring the physical world closer to the digital world.

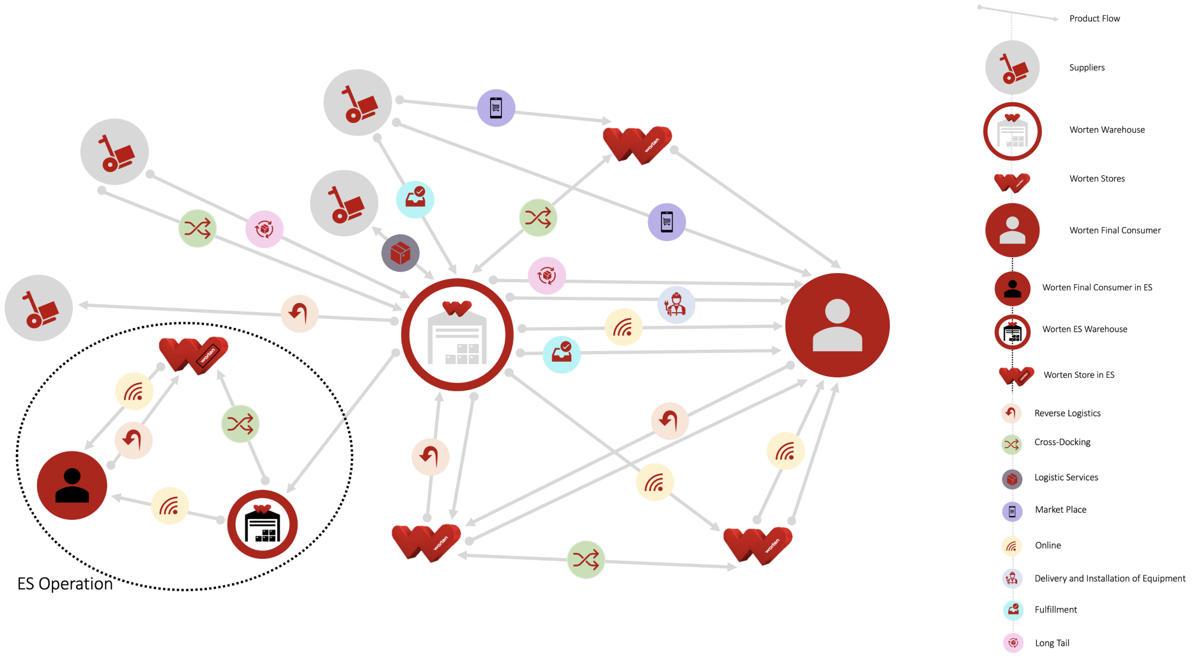

Figure 2.1: Supply Chain as is (Today)

2.4 Warehouse Description

The present study will be developed and implemented in the future at Worten's warehouse. Due to the complexity of the warehouse operations, this section will be dedicated to first explaining the main flows of the warehouse, then describing the layout as is, and finally, explaining in more detail the flows of the area that will be intervened.

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, is open 18 hours a day, with a workforce of 371 workers, 69 in the office and 302 in the operation, split between two shifts (8am - 5pm and 5pm - 2pm), storing around 263 657 different Stock Keeping Unit (SKU)s and about 2 978 492 units in inventory[2], that is part of the portfolio of products sold by Worten.

In terms of the types of different SKUs in the warehouse, there is a first differentiation based on the dimensions of the products. There are items classified as 708, which are small appliances and electronic devices of small proportions, from hair dryers to microwaves. Within this typology, some items are 708 but are of high value, such as mobile phones, computers, iPads, cameras, or those with extremely small dimensions such as memory cards and pens, which are stored in a different area of the warehouse which is more private and with restricted access.

The 701 items 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, as this presents greater restrictions. As this typology of items will be the focus of this project, this entire area of the warehouse will be explained in more detail.

2.4.1 Warehouse Main Flows

This section of the chapter will look in more detail at warehouse flows. Initially and from a macroscopic point of view, the flows are separated into inbound (coming from the reception) and outbound flows (heading towards expedition).

Besides inbound and outbound, flows are subdivided into Business to Business (B2B) or Business to Consumer (B2C). In the inbound branch, regarding the reception of goods, these are always considered B2B, which means that the transaction of flows occurs between the suppliers of the goods and Worten. Subsequently, this flow can be Long Tail, PBS, or Pick by Line (PBL). On the outbound branch, or expedition, the items are divided into B2B and B2C depending on whether the recipient of the purchase orders are Worten stores or end consumers, respectively. When orders are B2B, they can be prepared either via PBS or PBL. If the order is to be shipped to the warehouse in Spain, it is always B2B, only from there on will be considered a B2C flow. If the goods are prepared for the end consumer, they can be shipped in two ways, via Online, with product type 708 or via SCED, with product type 701, both for Home Deliveries (HD).

Now we will explain in more detail the terms Long Tail, PBS, and PBL[3]. In figure A.4, in appendix A, the colors of each box refer to the color of the label placed on the items, called inbound as iLPN and

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[2] DATA Obtained: 27th of December, 2021

[3] Only flows relating to the products of big-sized appliances will be explained in detail.

outbound License Plate Number (oLPN).

Long Tail, is the name given to items that Worten does not physically keep in stock and which are ordered from the supplier at the exact moment the consumer places an order. These products are defined for its their demand variability being very high and inconstant. This process is successful due to the constant sharing of information from the supplier on what their stock levels of each item are and also their delivery times.

PBS, corresponds to the orders preparation for Worten stores. When these products are received in the warehouse, they are then put away, and later, waves of picking are launched in which the respective pallet is built to be sent to the stores. The type of products included in this flow, which requires storing a safety stock to cover the variability of demand, is normally defined by the fact that its suppliers have low service levels, which means that they are then unable to meet short notice orders already placed, in terms of their delivery in the required time window.

The understanding of product types and respective flows (see appendix section A), inside the warehouse is essential to achieve greater organization with the attempt of clearing operational bottlenecks when it is known in advance where and when they occur, trying to meet the consumers' needs as much as possible: on-time, in-full.

There is still another important flow to mention that is not directly related to the operations at the Worten warehouse itself, but which will be very important as the project progresses, which is a second warehouse. The space in these external warehouses are rented (3PL service) from another company, where it is stored big-sized products that cannot fit in the Azambuja warehouse (due to the lack of space), as well as a repair area (in one of the three spaces rented), where Repair of Damaged Products for further outlet selling (UTRAD) is located. The UTRAD is an area of Worten to which the damaged products in the warehouse, including breaks, are sent.

2.4.2 Warehouse Layout

By entering this sub-chapter, it is already possible to understand all the main warehouse flows and how they work. The figure 2.2, shows the current first and ground floor plan of the warehouse, to get a more concrete view of the locations intended for the activities mentioned above.

The area corresponding to product 708 is on the right-hand side of the warehouse, and typology 701 is on the left-hand side. In green is the inbound area, i.e. the area for receiving goods, which extends the entire length of the warehouse. When the goods are unloaded from the trucks in the reception area, they wait on the loading lines to be checked. Some of them still go through Quality Control (QC), where the products are opened and repackaged, and only then the put away process will be performed.

The central part of the warehouse is where the processing orders of 708 goods, for stores or end consumers takes place: firstly the Put to Zone (PTZ), then the Put to Light (PTL), and finally the assembly of pallets with the products coming from the aforementioned zones that now derive in the Put to Store (PTS) area. The processing of online purchases is also located in this central aisle.

In the yellow section of figure 2.2, the pallets are wrapped either manually or with the help of robots before being placed on the dispatch lines.

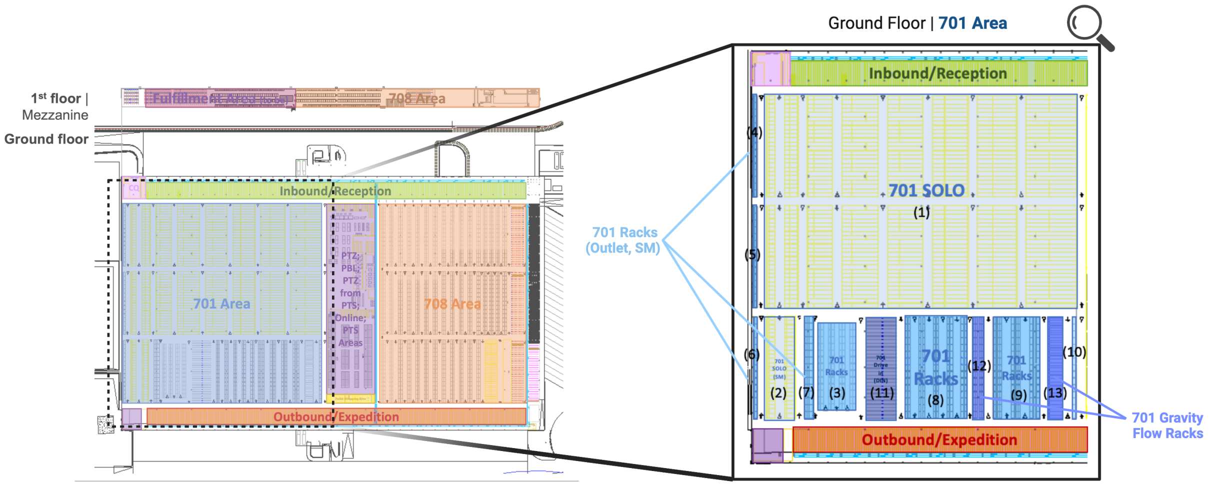

Figure 2.2: Azambuja Warehouse Overview on the left and a Zoom In of 701 Detailed Layout on the Right, 2021

Big-Sized Appliances (701 area)

Now, it will be explained in detail the different types of structures that the warehouse has at the moment, which families of products are destined for each space, and why, regarding the area of focus destined to Big-Sized appliances (701). The warehouse area for 701 is destined for big-sized appliances from washing machines to televisions and refrigerators. This area does not require any additional security in terms of theft prevention because the products here are large, which implies a different type of handling, requiring 100% use of additional equipment for transport such as reach trucks with clamps, powered stacker trucks, and powered pallet trucks.

The largest area of the entire space surrounding 701, is the “solo”, with 11 290.87 m^2 in total, about 25% of the entire warehouse solo floor, with a useful storage area of 8 513.39 m^2 discounting the circulation aisles. In this area, items are arranged in block stacking. Block stacking means that the goods are stacked on top of each other in accordance with a stacking factor that is indicated on the items package, previously defined and studied by the supplier so that the equipment is not damaged and is to be delivered later in ideal conditions. However, this stacking factor always has low values to give a safety clearance both in terms of storage, handling, and/or preparation. 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, thus requiring large extensions of floor space when aiming to store large amounts of stock. Also, this storage method does not make use of all the warehouse height. We will see in the next section section 2.5 that this is one of the major driving reasons for the development of this project. The area called ”solo” are represented in figure 2.2 on the zoom in part, on the right side, by numbers (1) and (2). In zone (2), Slow Mover (SM), are locations of goods that are less demanded by consumers and consequently have a much lower turnover than those stored in zone (1). In terms of structures, observing figure 2.2, there are 3 different types: conventional racks, represented by numbers (3), (4), (5), (6), (7), (8), (9), (10); drive-in racks (11); gravity flow racks (10); (12). The racks found in zones (4), (5), (6), are where items that are also slow movers are kept, but have very low popularity and do not justify occupying a location on the floor, goods that will be sent to the Worten Outlet in the future, or discontinued lines that can no longer be sold to the consumer. The racks in zones (3), (7), (8), (9) and (10) contain products where there are few or even only one unit and it is not justifiable to occupy a floor location with this product. All the aforementioned racks are conventional, consisting of a framework, with rails, which enables a mass storage of goods unitized on pallets. The Drive-in Racks (DIN), zone (11), essentially store products with a flatter shape, allowing great storage in height and depth, such as induction hobs. These structures have several compartments, and the same item is always stored in the same column to reduce picking errors. The Gravity Flow Racks, zones (10) and (12), is where all the televisions are located. Gravity Flow Racking is a storage system that depends on gravity flow to load, sort out, and recover put away packages, aiming to expand space, efficiency, productivity, and increase safety. Ideally, the bottom portion containing the ’swivel rollers’ is designed to support more robustly televisions larger than 70 inches. Zone (12) uses a push-back system inside the structure.

2.4.3 Warehouse Operations regarding 701 area

All operations involving the study area are detailed in flow charts presented in the text and also in the appendix section A. In this subsection we will discuss the inbound operations that occur when receiving goods, checking in all items and verifying purchase orders, how the put away of products is processed as well as the respective characterizations of items locations, and finally the compacting activities that will be explained later on.

Inbound Operations

Firstly, the inbound flow will be addressed and it is represented in figure A.7, in appendix A. Some important aspects to highlight in inbound operations are:

- New agreements to be implemented with Worten’s suppliers in order to pre-arrange their delivery time so that a daily planning of deliveries can be drawn up, benefiting both parties, making deliveries faster and more efficient.
- On 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 QC team accompanying the unloads has a priori a list of the trucks and goods to be inspected. The administrative office, together with the sales and customer service department, carries out a study on which products have the highest percentage of breakage when handled in the warehouse or during transport, and which have the highest number of complaints from customers, and on this basis the daily inspection sheet is formulated. When a truck arrives that is going to go through QC, 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 Portable Digital Terminal (PDT), a device Radio-Frequency IDentification (RFID), which checks the purchase orders for damaged items, this process is described in the figure A.8 in the appendix section A. At this point of checking, iLPN are created according to a colour system already mentioned, as can be seen in figure A.4 and A.2, both presented in Appendix A, and placed on the products according to the quantities that are to be stored together.

Storage Operations

When entering the warehouse, if the product is new, meaning that has entered for the first time, it needs to stop at the Cubiscan. The Cubiscan is a machine that measures the product's parameters, that is: its height, length, thickness, weight, volume, base area so that a correct location is assigned according to its type and specifications to be aggregated in the system for that particular SKU. This procedure is done for all new products, however, when they are big-sized appliances, they are also configured near the Cubiscan area, however, the machine is not used, as it only handles smaller items, so a balance is used and all other information is removed manually using measurement objects.

Regarding storage operations there are three main activities: put away, compacting, and replenishment. Put away is a follow-up to the check activity that was explained previously. When the reception of goods is finalized and the Advanced Shipping Notice (ASN) 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 items like the one read. However, the system does not immediately show if it is possible to store that specific number of units correspondent to that purchase order in a specific location, it is also necessary to perform an inquiry to the location in the PDT and then the number of units that are at that moment in that specific location is given. Thus, the operator carries out the put away process of the items in the suggested locations, as can be observed in figure 2.3.

Compact is an activity only carried out in the 701 solo area, with the aim of making it possible to add similar items every day in order to occupy fewer locations, increasing its percentage of occupancy and thus freeing up new spaces for future supplies. This flow diagram is presented in figure A.5 in Appendix A. Ideally, the location area should have and occupancy of around 80%. The objective was set to gain

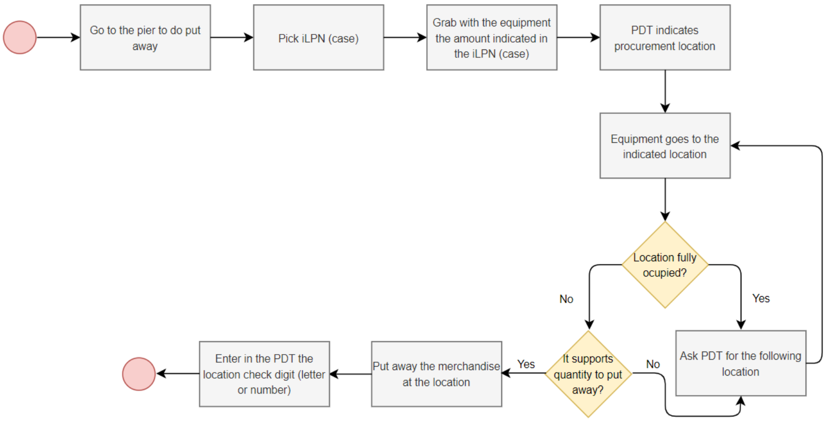

Figure 2.3: Diagram of the Put Away Activity

about 200 m^2 of floor space with this operation per day. It is important however to take into account if new stock of the same item will arrive in the next day, as the products should be moved the minimum, to reduce damage and resources usage.

In storage locations with the exception of DINs and solo area, they are always divided into two parts, a reserve where products can be stored in bulk called reserve locations allocated through a random assignment policy and a forward area where products must be at a lower level so that it can be removed quickly and easily, this is called active locations. Part of active locations can also be assigned through a random assignment policy only because there is not an SKU there at the moment. Thus, locations at the picker level are called active locations and at higher locations, they are defined as reserve locations.

The replenishment activity is very important because it is essential that when picking an order, the picker when stopping at a location, has enough quantity of the items needed in active locations. So, the replenishment activity is in part a let-down of the products so that the active locations are never empty.

These locations given by the PDT when products are put away are randomly generated by the Warehouse Management System (WMS), which then searches for the smallest possible location according to the items' properties.

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, exists 23 locations with different dimensions designed to store items with distinct properties, volumes, and quantities, as can be seen on the left side of figure 2.4.

There are 9 circulation aisles: GB, GC, GD, GE, GH, GK, GM, GN, GP. The code marked on the floor for each location has the following terminology: ***[AisleNameXXXA *blank* XX *blank* X]***, as it is represented in the figure 2.4, zoom in, on the right side.

This ground storage system has reduced efficiency, and there are no reserve locations in this area, they

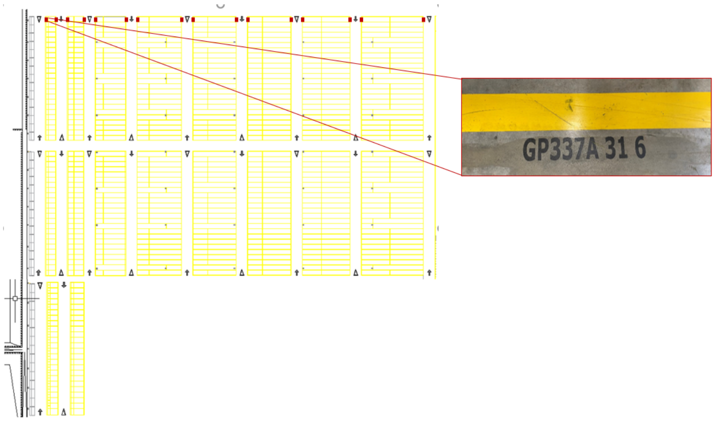

Figure 2.4: All types of locations 701 solo, and example of a location code position

are all active. Thus, each location can only hold one SKU at a time. Only when all those units of the single SKU have been removed from that lane, it becomes free to be occupied by a new one. As mentioned earlier, 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 to 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 find it or to retrieve it. There is a trade-off between storage and handling efficiency, and in this instance, the fewer items moved, the higher the handling efficiency. In figure A.3 in Appendix A, it is possible to observe this phenomenon.

Outbound Operations

Regarding the preparation of orders for 701 products, there are two ways in which these can be dispatched: through PBS or SCED, both flows are represented in the Appendix A, in figures A.9 and A.10, respectively. When orders follow a PBS flow, it means that during picking, the items are placed on pallets by stores, 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 sealed. Pallets are left on the outbound area identified in figure 2.2. The transport made to Worten stores is carried out by an internal operator, Luís Simões. This operation is carried out from the warehouse opening at 8am until it closes at 2am, daily. If the flow to be followed is through SCED, which means that the orders are collected for the consumers to be delivered directly into their homes by *Totalmédia*. Only one picking is done at a time because the SCED does not compile products onto pallets, as these are sent in bulk. When the picking activity is finished, the products are left on the loading lines but in the reception area, figure 2.2. This service only starts at 5pm and ends around 2am, daily. QC flow regarding SCED operations can be visualized in figure A.6 in Appendix A.

2.5 Problem Statement and Objectives

Throughout this chapter, it has been contextualized some of the challenges that the operation faces every day, namely in the area of big-sized appliances. Hence, this section will define the problem and explain the project's objectives.

As mentioned before, the starting point of all flows is from the warehouse in Portugal. Thus, it is increasingly necessary to seek cost-effective ideas to keep up with all the growing demand and also the ever-increasing demands of consumers in an ever-changing world.

The sales of big-sized items at Worten have been growing over the last few years. The stock level of this type of items has increased as well as the number of SKUs. 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. 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. Also, although it is a large area of about 11 000 m^2, the maximum storage space efficiency achieved is 56%, being this value always the target.

Therefore, Worten proposed the development of a project in which the main objective is an intensive study of this area of the solo, in order to design and implement in the future a structure that can occupy the entire height of this storage area allowing the total occupation of this space. This project pretends to identify the products or families of products (according to depth and width of range, physical characteristics, average stock over time, among others) that can be stored in height; identification and proposal of a storage structure; designing the idealized structure; procurement of suppliers that will conceive the structure and comparison of alternatives; realization of an as is versus to be analysis in the warehouse.

2.6 Summary of Chapter 2

This chapter is dedicated to describing the operations of the Worten warehouse in Portugal. Due to its complexity, it is showed the supply chain network growth, explaining all flows, warehouse layout, and describing in detail the most relevant operations involved in the area to be intervened. Finally, the problem felt by Worten is contextualized and the objectives of the project at hand are presented in order to mitigate and even try to eradicate some of the problems encountered today in the operation. The next chapter will be dedicated to the literature review, which methods will be used to explore all the possibilities that must be considered for the elaboration of the methodology that will always be aligned and aimed at the achievement of the solution of the proposed problem.

3. Literature Review

Up to the present chapter, a contextualization and description of the problem at hand have been carried out. From this background, a theoretical basis founded on the literature review will be provided, in order to analyze which are the best hypotheses to approach the problem under study. Consequently, this chapter is divided into five major sections. The first one refers to warehouses as is the center of the projects´ development. Furthermore, in the second section, the main operations and the correspondent movement of goods in a warehouse will be covered, with a greater focus on storage and picking activities. For this reason, it is executed a warehouse microscopic view, divided into layout and which structures could be considered for large domestic appliances, including the as is system. The penultimate topic is related with the tools and indicators as simulation and cost-benefit analysis, that considers the feasibility of implementing a certain project. The last section synthesizes the essential themes reviewed in this chapter, to define a working methodology for the problem.

3.1 Warehousing

As the aim of this project is the design of a storage structure in a warehouse, the concept of warehousing emerges naturally as a major focus of the research. However, it is not possible to make considerations about storage without first looking into warehouse matters. This being said, the first section refers to warehouses and how they are part of a supply chain as well as their importance, going through some particularities of retail warehouses, including warehouse management and design considerations.

The definition of warehousing given by the *Council of Supply Chain Management Professionals* is ”The storing (holding) of goods” [14]. However, more sophisticate definitions were found [15], [16], [17], stating that a warehouse must serve as a trans-shipment point because the products entering must be dispatched as quickly as possible. The purpose of warehousing is not to store products indefinitely [18].

Nowadays, warehouses have several functions and incorporate several flows of a wider network. In addition to traditional warehousing, warehouses also perform services such as cross-docking, postponement, intermediate, customization or sub-assembly facilities, sorting centers, fulfillment centers, and reverse logistics. All this growing involvement, the new e-commerce platforms and globalization of storage services as well as its networks, plays a major role in a company's success. This allows greater benefit to be derived from these facilities, which are no longer solely for warehousing, including the reduction of independent operating costs due to the centralization of activities [19], [20], [21], [15].

Warehouses are an essential part of the supply chain [15]. The combination of product demand and supply at all levels of the supply chain culminates in one focal point, which is warehouses [20]. On a supply chain network, the warehouses are represented by the operational nodes that are responsible for the efficiency and effectiveness obtained within the company's ecosystem [1].

3.1.1 Retail Warehouses

A retailer is defined as an organization or even a person who buys products from a manufacturer or distributor and then resells it to the end customer [14]. The retail sector these days is increasingly competitive and needs greater dedication in the areas of operational and customer efficiency. Gradually, consumers are looking for higher service levels at reduced prices. In turn, retailers seek the opportunity to sell a wide range of products, in numerous outlets, profitably and at lower cost [22]. Retailers can match demand and supply with accurate sales forecasts, supply flexibility and stock storage. Nevertheless, before demand is estimated, manufacturers allocate their products to stores, and retailers answers as passive recipients of these goods. In recent decades, retailers manage the supply chain from manufacturing to consumption, passing through stages such as controlling, organizing and managing, taking over the handling of the supply of items in response to the demand identified by their customers [22], [23]. As a result, sales forecasting is a critical point in this type of industry. The retail sector is an industry with great, if not the greatest logistical and financial difficulties. A retailer needs to be able to deliver the right products, at the right places, at the right times without losing profits [24]. The flow of goods from a warehouse can be broken down into three subsystems, distribution centers, transportation and warehouses. It is important to note that each of these subsystems has its own logistics network that will have to be shared to function as a whole [24].

The changes in retail came in response to the increase in audits carried out between the warehouse-to-store distribution flow. This has enabled an increase in the number of products sent by retailers to distribution centers, and greater control of the distribution center-producer flow [22]. Shorter lead times for orders, more delivery windows, and reduced quantities of products are the outputs of a reduction in stock, which has allowed the adoption of a constant flow of products in a given supply chain. This was also possible due to the centralization of products in warehouses and reorganization of the logistics network allowed retailers to increase efficiency [22].

New traditional retailers have started to expand their horizons, keeping up with an ever-changing industry, using new online business models where it is possible to provide better services to their customers [25]. These services range from online shopping, home delivery, and click-and-collect services that have enabled retailers to achieve a competitive advantage in the industry. However, all these new challenges of e-platforms [26], represent significant logistical difficulties over the last mile, and extra costs that will take time, effort and resources to resolve [25].

3.1.2 Warehouse Management

Warehouse management functions include warehouse organization definition, inventory control (on location), resources and activities planning, and information management [27]. The warehouse can be studied from three different angles: processes, resources, and organization. The explanation is that the processes are all the procedures performed from the arrival of a product until it is departure [1], [15]. The resources are crucial to support operations starting with employees, going through all the necessary equipment to perform the needed processes and finally all the tools used to manage a warehouse. The term organization encompasses all the planning and controlling activities needed to give operational support [1].

Over the years the evolution and innovation of warehouse technology are tremendous [1]. As new technologies emerge, warehouses are becoming increasingly automated, which meets the needs for increased operational flexibility along with growing consumer demands [20]. The challenges in a warehouse most researched over the last three decades are layout design, product allocation in order to maximize space and minimize time, material handling and costs [28]. The most important warehouse sector is the one that is related with storage [29]. Intelligent inventory management can lead to a significant reduction in warehousing costs. A proper allocation policy can reduce the time needed to store and to pick orders, by 50%. Also, by evenly dispersing activities among warehouse subsystems, congestion can be avoided, and activities can be properly balanced among subsystems, increasing processing capacity [30].

3.1.3 Design Considerations

A big challenge when setting up a warehouse is its design, because of the endless possibilities that can be adopted, everything should be monitored closely. The design consists in four stages, starting with a functional description, technical specification, selection of the equipment needed, and proposal layout [1]. In each of the stages described, four key performance indicators should be evaluated being costs, throughput, storage capacity, and response times. At each step, some decisions must be made, and sometimes the trade-offs that need to be considered collide with the project's main objectives [1]. A design approach needs to consider a great number of technological tools, planning, and control methods to elaborate a ranking list, establishing priorities. This need is because the challenges faced by the design of a warehouse are not defined properly and cannot be split, it should be kept in mind that every decision is interconnected, significantly affecting how operations flow. It must be considered a combined approach that consists of analytical and creative aptitudes. Another evidence supporting a possible warehouse design that can only be judged in part is due to the existing difficulties when forecasting the products that will be stored and also the unpredictable capacity demand [1].

Respecting warehouse organization, at the design stage, the most crucial choice is the characterization of the process flow [1]. Important decision examples on this subject are, the necessity of a replenishment process due to the use of separate reserve areas, the retrieval of products in batch, or zone partitioning of the picking area. All of this demands a process of consolidation or the use of distinct lanes for storage and retrieval. The paper [1], also tries to put these decisions from a hierarchical point of view, evaluating a variety of performance metrics contrasting with different architectures. Six main stages are raised comprehending the concept phase, data gathering, function and technical specifications, selection of methods and required equipment, layout of the area, selection of planning and control policies [1]. All stages previously mentioned are comprised of three-dimensional levels: strategic, tactical, and operational [31], [1], [32], illustrated in figures B.1, B.2, B.3 presented in Appendix B. Decisions regarding the process flow and the level of automation implemented are part of the function, technical specifications are inserted in a strategic dimension. Essential activities that are considered to have a long term impact and involve very costly investments, such as storage and sorting systems are considered from a strategic point of view. Major decisions about warehouse systems and needed processes, named process design are covered in this axis. Process selection can be broken down into two smaller sequential situations that look at economic factors and technical skills [1]. For the same reason, considerations regarding storage systems are also at a strategic dimension [31].

The article [31] also clarifies that adding to the storage, the warehouse layout is also a strategic consideration since it has a great influence on long-term profitability. In contrast [1], refers that the dimensioning of these systems and the warehouse layout itself are both tactical deliberations.

Finally, control policies are found at an operational dimension [1], [31].

In conclusion, strategic and tactical choices determine and influence what must be executed at the operational level [1], [31]. The interfaces between processes are defined as design challenges in these two axis. Operational policies have less interaction and therefore can be studied separately [1].

Always keep in mind that all the interconnected decisions have a horizon application in terms of being a long term, medium term, or short term solution, whereas higher level clarifications generate lower level restrictions upon design challenges [1]. It is common to have to cluster similar problems that need to be addressed at the same time. An ideal design technique will be to first optimize simultaneously the universe of warehouse sub problems, clearing the way until the objective can be achieved. In the first phase of a project, it is outlined in low detail and developed in a more complex form in forthcoming phases, using a top-down approach [1].

Above all, to be able to evaluate the performance and accuracy of a warehouse design, it is possible to establish some indicators that allow measuring the productivity of the designed solution: operational and possible investments expenses, volume flexibility, throughput, storage capacity, response time, and quality of order fulfillment [1]. Each Key Performance Indicator (KPI) has a different degree of relevance depending on the type of warehouse in question. The storage capacity is a key design factor. When scheming a warehouse, the most important goal is to have the maximum throughput possible with the minimum investment and operating expenses [1]. The paper [33], addresses the essential criteria for warehouse design.

3.2 Warehouse Operations Management

In the second section of this chapter, topics on operations will be addressed namely main warehouse operations, followed by the traveling of a product in a warehouse, giving more emphasis to the storage and picking processes which will be the most important for the focus of this project.

3.2.1 Operations

The needs of more than 20 years ago are still felt today, the continuous search for increased productivity in operations and reductions in response times, have an enormous impact on how it can work towards a more smooth and efficient logistic flow [1].

Warehousing activity is defined as the organization of products in a warehouse in order to maximize the use of the necessary space and effective handling of materials [15]. One of the main difficulties is to forecast demand that varies over time and therefore it is a complex task to design warehouse systems with an accurate capacity. The capacity that a warehouse can store and process is given by the quantity needed to store the incoming items in order to achieve a specific service level that directly affects the space availability [34].

Operational characteristics and measures are necessary to determine the best layout for a given warehouse. Examples of these characteristics are modularity, adaptability, compactness, mobility distribution, accessibility, and flexibility. This allows conditions to be met for future adjustments and possible changes of the system which improve the use of space, minimize congestion and the necessary movements [29]. Intense competition leads to the constant development of operational and distribution networks with an increasingly efficient performance [15]. The cumulative availability adoption of different information technologies such as bar coding, Radio Frequency (RF), and warehouse management systems like WMS facilitates warehouse operations. This evolution allows the monitorization in real time of all the operations to be performed in a warehouse, as well as the interaction with other nodes of the network that can be an added value to the entire system's operation [15].

The main operations that are carried out in warehouses, are receiving products from suppliers, storing, receiving purchase orders, and executing them, consolidating all the items in an order, and finally dispatching them [15]. The inbound and outbound flows relate to receiving and shipping respectively, meet in the warehouse. In the inbound flow, products arrive, are unloaded, received, and placed at the correspondent location. Then, once the location of the product to be picked is selected, it is prepared and sent in outbound flow to the consumers [15]. Both at a customer and at a warehouse level, some key management factors continue to be prioritized, such as accuracy, on-time, flexibility, and the ability to respond to all customer requirements [16].

3.2.2 Movement of Goods

The movement of goods through the warehouse may be broken down into numerous separate phases or processes, as previously mentioned, which are: receiving, storage, order picking, and shipping [1], [17], [35]. When an item arrives at the warehouse, the reception process starts. In this stage, the products go through a checking operation. When this activity is over, the items wait to be transported, and the storage process starts. The items are led to their storage locations. It is also enhanced the difference between two kinds of storage areas, one is the a reserved area where products are allocated in bulk, which is the most cost-effective way to store goods, and the forward area where products are already prepared separately ready to be picked. The activity of replenishment takes place when the products need to be moved from the reserve to the forwarded area. The storage action comes to an end, when the products are retrieved from their storage locations executing an order picking process, manually or automatically. Once an order picking is executed, consolidation can occur, which means gathering the products that belong to the same purchase order. The process of examining, packaging, and loading an order into the designated transport is accomplished at the shipping area [1], [35].

3.2.3 Storage

The activity of assigning goods to suitable storage locations is essential as it influences movement, time, cost, throughput, and productivity [29]. A given SKU can be allocated to multiple zones within the warehouse. In the design concept, the range of sectors and the allocation of the respective ones should be specified. After this step is completed, some questions still must be addressed, such as the quantities to be stored, and if necessary, which transfers between departments should be considered for a certain SKU. Essentially there are three strategic points to consider. The first is the quantities of each SKU that should be kept in stock, then it is important to analyze how often this stock should be replenished, and finally, where these units should be stored in order to facilitate other operations involved [15].

There are three types of storage policies which consist of random storage, class-based storage, and dedicated storage. If products can be kept anywhere in the storage space, it is classified as a random storage strategy, and the operator can choose the location that seems the most suitable. If the storage area is divided into classes, considering several aspects, for instance, demand and/or turnover rates, it is named class-based storage strategy. This strategy implies a specific area for the storage of these products accordingly with each formulated class.The last strategy intends to store products in proximity by product family in case they are used at the same time or bundled [1], [32], [15].

When speaking about dedicated storage, a specific location is used to store an exact item. Summing up, randomized classifies all products into a single class, and dedicated storage uses only one class per item. Both policies act as extreme cases of the class-based storage one. If the storage system used includes forward and reserve areas, both need to be specified in terms of the storage policy. These policies should go hand in hand with replenishment policies including storage quantities and turnover periods [1], [32], [15]. An example of class-based storage is illustrated in figure B.4 in Appendix B.

When one needs to allocate products to a specific location, different driving forces can be used. One of them is popularity [1]. This is measured by considering the ratio between the number of storage operations per unit of time. Therefore, a decreasing popularity list is created, where the most premium locations of the warehouse must be destined to products with a higher popularity class. Another criterion also used is the maximum stock, this is defined by the maximum warehouse space allocated to a product class [1]. So, the maximum stock classes are listed in an increasing way, and those that have a lower value are assigned to the most premium places in the warehouse. Finally, the Cybe-Per-Order Index (COI) is also used, which is defined by the ratio between the maximum storage capacity and the number of operations performed per time unit [1], [36]. This policy immediately considers two aspects, both the popularity of a given SKU and its spatial storage requirements. Lower COI values are for the most desirable locations. The policies described can be implemented depending on the systems used in the warehouse, i.e. which storage unit, warehouse movements influence the concept of most premium locations. Some factors are decisive in finding the most suitable storage efficiency and also usable warehouse capacities, such as seasonality, storage strategies and characteristics [1].

Regardless of the product to be stored, the functions required to perform this activity always remain the same, as well as the objectives to be achieved: maximizing space, equipment usage, manpower, accessibility, and last but not least, goods protection [37].

3.2.4 Picking

Concerning operations itself, the most expensive activity in a warehouse is picking products to complete purchase orders, order picking. This decision affects the operation at various levels so it should be considered as a strategic choice, as defined in section 3.1.3, [1].

A picking zone is an area of the storage location that is designated to carry out a picking activity [15]. Generally, this is a small area so that a high extraction efficiency can be obtained, as well as familiarization of the operators with this space. Each zone has a limited number of SKUs allocated to a certain space, which is within an area. This allocation directly influences both storage capacity, inventory tracking, and also the picking of products when executing a purchase order during the picking process. There are several picking methods that can be adopted such as: single order picking, batch selected during or after picking, sequential picking by zone with a single order, sequential picking by zone with batch, simultaneous picking by zone with or without batch in zones [15]. These events can be performed manually or automatically. The equipment to perform picking activities is used throughout the warehouse for retrieving goods from the storage system, for instance, the most common one is a reach truck. Besides this, several other resources involved in warehouse operations need to be enhanced, such as storage units and systems, order picks auxiliaries, computer systems, sorter systems, palletizers, truck loaders, and dedicated personnel. Looking at technological capabilities, storage unit and methods,as well as the equipment, must be suitable for the products, and cannot conflict, or be incompatible [1].

3.3 Warehouse Layout and Storage Methods

In the last section concerning warehouses, some important considerations concerning the layout will be explained in order establish a more conscious point of view, regarding which system is used nowadays in the area to be intervened, and also which structures are to consider for this space.

3.3.1 Layout

One of the main warehouse goals is to store products, it is important to start layout considerations with an examination of what kind of items need to be stored. Handling costs are achieved by bearing in mind the distance traveled in the function of the volume and the area filled by the products. It is necessary to emphasize that the products' dimensions, as well as the way they are stored in the warehouse, are direct inputs on how efficiently they are handled [33].

When creating a warehouse layout, considering as input, demand, material handling, operations, storage allocation, number of aisles, as well as their position, orientation, length, and width, are central considerations [2], [29]. An example of layout considerations is illustrated in Appendix B. The layout issue is seen as critical by businesses in order to boost their competitiveness [38]. Layouts that minimize handling distance are different from the ones that minimize storage volume. The overall design should be symmetrical [33]. A warehouse is generally designed to have several aisles arranged in parallel, and products stacked on top of each other (block stacking) [30]. If one of the goals is to increase storage space, for instance, a deeper stack means fewer aisles needed which results in higher savings [33].

In this phase, related to layout deliberations, one should also consider the arrangement of products in terms of their allocation in premium locations in the warehouse so that the operations involved are facilitated. When there are variations in stored products, they automatically differ in size, weight, demand, among others [30]. Depending on the allocation of products to specific families, different types of storage and retrieval can also be considered. A basic concept often used to allocate products is to keep trendy items (with more frequency of checkout for instance [30]) in more premium locations. A premium location is one that allows easier and quicker access to the stored products.

Complex layouts with several aisles, asymmetrical stack boundaries, cross aisles, several access faces to the stacks, or numerous radial aisles do not add significant compensations over simpler layouts [33]. When designing a layout, it must be kept in mind that there is no one strategy or approach that is ideal for all situations, due to the huge list of factors that affect the operation in a direct way. Therefore, choosing the optimal plan for a specific scenario is a complex task [28].

Over the years, some studies about this subject were made. In the paper prepared by [39], a simple technique is used to design the architecture of a rack when the highest volume is due to repeat orders. Class-based strategies as described before in section 3.2.3, are used in order to maximize space and save on materials handling. Hence, a division is made into three phases consisting of the aisle layout and dimensions of the storage area, in a second step the material allocation, and finally the space allocation [39]. A warehouse layout approach is also given in [37].

More recent studied problems consider both horizontal and vertical movement costs of operations [40]. Three main groups of costs are highlighted when comparing different interior layout designs. The first one is the cost of internal handling distance, the second is the warehouse space cost, and finally, the last group is the building perimeter costs [41]. Simulation models should be used to access the viability of alternative layouts occurring on a random basis [33].

3.3.2 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 one another on the warehouse floor, stacked to the maximum height allowed, between aisles. Considered factors for stacking the goods are, pallet conditions and heights when products are stacked but the system is palletized, load weights, safety restrictions, 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 [42]. This method stores large quantities [31], and can be considered in any warehouse with a wide floor area, however, is not an easy task 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 [31]. 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 [42].

The Chemical Week paper [43], states that when a multi-unit storage area is partially occupied by a material, occurs a phenomenon called ”honeycomb allowance”[1]. This empty space is the result of an operational strategy designating only one SKU to each location, so that when the entire product is shipped that space is on stand-by, waiting for the same item to be stored there. In some circumstances, it is possible to reallocate items regularly in order to obtain a higher occupancy percentage of a given location. These re-allocations are a factor in the inefficiency of the system [44].

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[1] Defined as the proportion of storage space lost as a consequence of inefficient utilization of all available storage space in a given location.

Some disadvantages [42], such as the fact that a space location might remain empty or partially empty until a certain SKU is supplied. When instead of a dedicated policy, a shared policy is used, one of the previous disadvantages is solved because with this system it is not necessary to have an exact location for a given SKU, i.e. any SKU can occupy any position as long as that location is empty. This policy makes better use of the warehouse space, however, it may decrease productivity in the picking process, due to possible constant variations in locations and position, since these are assigned according to whether they are free or not, and not according to a zoning tactic or others [42].

When space is limited and a large number of SKUs need to be stored in a certain area, a shared strategy can be used, particularly when the several SKUs are low on inventory [42]. This is justified when an SKU does not enter the warehouse for a period of time, and a specific lane is unused waiting to store it, the system becomes less efficient due to the idle space. A shared strategy proposes the opposite of honeycombing, which means that different SKUs can be stored in the same lane. However, it can result in the blockage of items that now become inaccessible. In contrast, when SKU quantities allow a position to be allocated to a particular reference, from the moment the first product is placed in a designated lane, it will only be stored in that position, avoiding the need for re-allocations or the trouble of items blockage.

An equally significant aspect respecting this storage system, it can achieve a greater number of items stacked per m^2 relative to the percentage of floor space occupied. However, it does not cover all shapes of products, i.e. items that are fragile, with uneven surfaces, or with low stacking factors, makes the system inefficient because it is not possible to take advantage of all the height [45].

Other articles [46], [47], [48], [49], [50], [15], [51], [32], [43], [37], [42] were studied to get a temporal perception of the type of studies carried out on a Block Stacking System (BSS) typology.

Structures and Systems to Consider

Before mentioning some typologies of structures with potential to be considered in the desired implementation, with the purpose of storing large domestics, some other considerations should be analyzed.

When talking about the layout of a warehouse, a number of storage-related issues may arise [15]. The first questions that arises are about the depth of the storage location, the number of locations with certain specified dimensions, maximum stacking height, angle of items position, length and width of circulation aisles, and finally distance between locations. Other important considerations such as the direction of aisle circulation, as well as the number of aisles, come into play, among others. These cautions encountered in formulating a layout directly affect the costs of building and also warehouse maintenance, handling of products, as well as the ability to be able to store incoming containers, the consumption of space, and lastly the use of equipment [15].

In the course of studying which storage strategy is the best, it needs to be studied if it is better to stack or to rack [45]. There are three main factors that influence the configuration of a rack: the item weight, how much product handling equipment is required, and how much space is available. The best approach to evaluating pallet storage options is to balance both the storage density keeping in mind its selectivity[2] and space utilization. Although a selective configuration is more usual, some alternatives may offer higher densities of stored products, such as drive-in or drive-through, push-back systems, among other examples where automation is privileged [52].

Over the years with the development of technologies, the actual use of high-density storage devices has evolved. There are two inventory management policies that can be applied to the types of structures to be treated, First-In, First-Out (FIFO), and Last-In, First-Out (LIFO) [52], [53]. 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 type of policy to be implemented is not important, first the type of system that is required is considered, and only then the most appropriate policy is determined [52].

- **Drive-in and Drive-through Racking (DIN)**

The Drive-in/Drive-through Racking type of storage structure is intended for high inventory levels, but with few SKUs. This is a form of dense storage, and due to the large number of pallets per SKU, racking can be used for fast-moving goods, however, the speed of movement within the structure itself is often low. The system consists of pallets being stacked on rail beams in racks, one on top of the other. Drive-in racks are typically built to a height between 10 and 11 meters and a depth of six pallets, although they can be built to considerably greater depths depending on requirements [11], [52]. In this type of storage, the policy to be used must be LIFO. Poor space management of the location occurs, usually, only 70% is used. Forklifts are the most commonly used type of equipment, they enter in the front/back of the structure to store or remove pallets, which are supported on rails. Each rail stores several pallets, which makes access to the first ones placed completely restricted. This style of racking is typically used for bulk storage of the same SKU, which makes restricted access no longer a concern [11], [52]. A illustrative figure can be observed figure B.6 in Appendix B.

Possible structure variations involve as in BSS ideology, products can be stacked back-to-back, i.e. two DIN´s placed in opposite positions, acting independently and accessible from both sides. The drive-through variation consists when there is the possibility for handling equipment to pass through one DIN and into another aisle. This variation is less used than the drive-in racks and is more applied for production rather than storage. Comparing conventional pallet storage, with drive-in/drive-through structures, allows very high utilization of the designated area, however, at the cost of limited accessibility. The approached typology could be a solution to alleviate the problem raised in the BSS solution, regarding the possibility of products breaking [54], [11], [52].

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[2] Selectivity in a warehouse is defined as the portion of units and cargo that can be accessed directly from an aisle.

- **Satellite, or Shuttle Racking**

In this type of storage, the layout is somehow similar to DINs. Pallets are held on two edges by flanges. Satellites are powered by batteries. Storage units are transported from the Inbound/Outbound location to the different levels, where they are moved to a buffer zone using a lift. The satellites load the unit and transport it to the designated location. The retrieval process is carried out in reverse order. In contrast, rotating satellites, work on multiple storage levels within the same aisle, adding a lift for vertical transfers. A different arrangement, allows the satellites to change not only the storage level but also the aisle. As a result, the satellites follow a rectangular grid of crossed lanes and aisles at each level. satellites are normally limited to a single storage aisle and a single level, in the most typical form [11], [52]. A summary of the four possible configurations of the system between three-dimensional axes, according to the movements of the satellites is illustrated in figure B.7, present in the Appendix section B.

When the number of pallets per SKU is high and can support a full queue, this storage typology is highly dense. Each of the rows is controlled independently, so SKUs can be placed with different requirements than those used in drive-in racking. This system uses a FIFO policy. There is a loss of space due to the possibility of losing one pallet size in height because of space needed under each level of pallets in order for the satellite to function [11], [52].

In contrast to DIN and BSS, this storage requires fewer pallets per SKU, which makes it more versatile [4], [11], [52]. Compared only to BSS storage that may require 24 to 48 pallets per SKU, by adopting a satellite racking strategy, only 10 pallets per SKU can be used, visualize in figure B.8, in Appendix B.

- **Push-back Racking**

Another storage possibility is called a push-back system that stores products in a dense form and provides independent access to each level. Push-back racking system uses multiple panels that can hold two to five pallets in a single deep row. Pallets are placed on inclined, gravity-fed rails, forcing the goods to the rack with consecutive loads. When a pallet is placed in front at the beginning of the row, the pallet that was there first is moved one position back. When unloading is being carried out, the first (front) pallet is always removed and those behind move to the front picking position. However, some control must be maintained over the speed at which the pallets are removed from the frame so that loads flow forward in a non-rapid manner [11], [52]. It is best suited to SKUs with low inventory levels, using for example four-level systems with depths of eight or more pallets. In height and depth, there is no need to always store the same SKU, as was the case with BSS and DIN. However, in push-back structures, for more independent access of items, the same SKU is stored in each row for easier handling. This system uses a LIFO policy. This type of push-back storage is far more versatile than DIN racking as each row of SKUs works independently and can be used in combination with other distinct structure typologies [11], [52], consult figure B.9 present in Appendix B.

- **Adjustable Pallet Racking (APR)**

APR, is the most common form of storage in warehouses. Pallets are placed on horizontal beams, parallel to the aisles, supported by a vertical structure. The structure is fixed to the ground, but the beams can be placed at different heights. However, although this structure can be adapted as needed, the stability of the structure must be recalculated. However, it is possible to support a wide variety of loads. In this and any other structural system, safety is a critical factor, as any failure may have disastrous repercussions (chain reaction, domino effect). Any beam that is damaged should be repaired immediately as it can compromise the integrity of the structure, and regular inspections should also be carried out so that such events do not happen regularly, and anomalies are detected [11], [52]. The main advantage of this type of storage, which has a single depth throughout the entire structure, is the ease of placing or removing a pallet independently of the others. This factor avoids honeycombing, as the occupancy capacity of each location is around 90% to 95%, [11], [52].

It is generally applied to companies that have a limited number of pallets per SKU and some restrictions on a FIFO policy. In terms of floor space occupation, this solution is more deficient compared to any of the others already mentioned, because it is only possible to store 2 pallets in this area [11], [52].

There is a variation of the one explained above which is double-deep racking. The only special feature is the addition of another structure which is the same but which both work back-to-back [11], [52], see figure B.10 in Appendix B.

- **Narrow-aisle Racking**

Narrow-aisle racking is another possible variation to conventional rack storage. Here, much narrower aisles, usually 1.8m or less, can be considered. In this type of aisles, it is possible to store more pallets per m^2 because of the higher height, denser footprint and due to the shorter aisles. As can be expected, it is more expensive to implement, as well as the specific equipment to handle the loads in these narrow aisles. Due to their size, the equipment in this storage is only used for this purpose and is not shared with other areas of the warehouse due to their specific characteristics. Normally, two operators are required, one seated maneuvering the equipment and another outside assisting [11], [52]. A scheme is presented in figure B.11 in Appendix B.

- **Gravity Flow Rack**

The storage system, gravity flow rack, in terms of selectivity and density of products possible to place in the structure, and the dynamic pallet mechanism is equivalent to the push-back system [11], [52]. Each row in the structure is made up of inclined roller tracks. Thus, the pallets are loaded on one side and picked on the opposite side. In this method of storage, as the pallets ”slide” with the force of gravity depending on the given slope, there is no need for the operator to check their rate of descent. Thus, it can be said that this system, in terms of safety, is safer than the push-back and DINs methods. Hence, it is possible to store a high density of SKUs, which in turn also increases the picking density with shorter distances traveled and a higher number of picks made per unit of time. A FIFO policy is adopted here. It is important to enhance, no additional use of any type of electrical power is required, this system works only with gravity [11], [52]. In dynamic structures, replenishment does not interfere with picking activity, which is not the case when the systems are static, where replenishment and picking must alternate. However, to replace the flow at the back, extra aisle width is required for this activity to take place [11], [52]. See figure B.12 in Appendix B.

It is presented a summary table with the respective advantages and disadvantages of each system typology 3.1, based on the information found in [11], [52]. Green symbols indicate an advantage and red ones indicate a disadvantage for the storage system. When there is no symbol, it means that nothing was found in the literature review for that specific topic relatively to that system.

- **Platform/Mezzanine**

Platforms[3] 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 [55], [56], [57]. See figure B.13 in Appendix B.

3.4 Design Validation

Coming to the penultimate section of the literature review, after having covered the basic theory behind both a warehouse and the operations that incur in it, this section essentially concerns the possible ways to evaluate a project in order to verify its viability. 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 latter evaluation method, two primary indicators are mentioned regarding monetary calculations, ROI and Payback Period (PP).

3.4.1 Simulation

Simulating the behavior of a real-world process or system over time is known as simulation [58], [59], [60]. Simulation creates an artificial history of the system and observes it to conclude the operational

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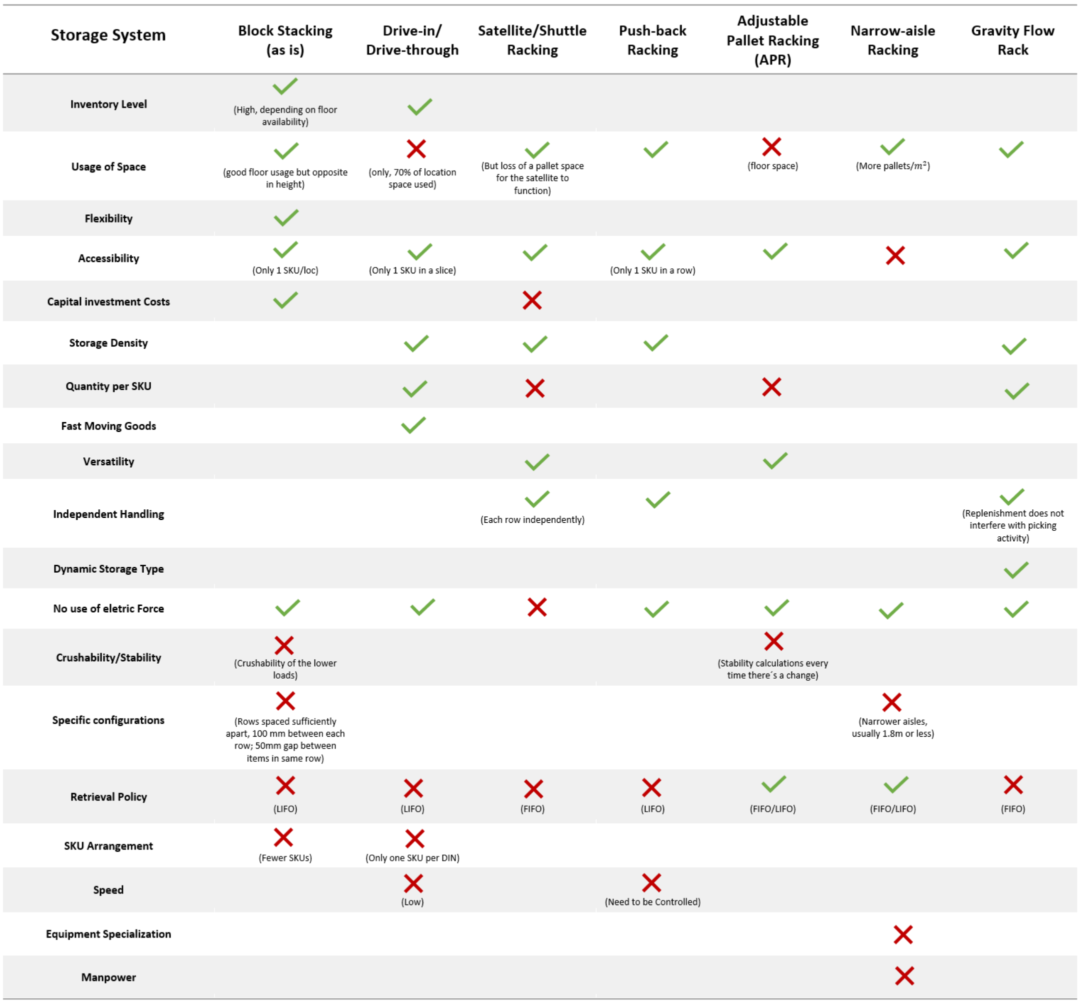
[3] The platform has not been added in table 3.1, because this is only a structural solution that is compatible with all the systems mentioned. No scientific papers were found about this solution.

Table 3.1: Comparative Table between the various Types of Storage Structures



Storage System	Block Stacking (as is)	Drive-in/ Drive-through	Satellite/Shuttle Racking	Push-back Racking	Adjustable Pallet Racking (APR)	Narrow-aisle Racking	Gravity Flow Rack
Inventory Level	✓ (High, depending on floor availability)	✓					
Usage of Space	✓ (good floor usage but opposite in height)	✗ (only, 70% of location space used)	✓ (But loss of a pallet space for the satellite to function)	✓	✗ (floor space)	✓ (More pallets/m^2)	✓
Flexibility	✓						
Accessibility	✓ (Only 1 SKU/loc)	✓ (Only 1 SKU in a slice)	✓	✓ (Only 1 SKU in a row)	✓	✗	✓
Capital investment Costs	✓		✗				
Storage Density		✓	✓	✓			✓
Quantity per SKU		✓	✗		✗		✓
Fast Moving Goods		✓					
Versatility			✓		✓		
Independent Handling			✓ (Each row independently)	✓			✓ (Replenishment does not interfere with picking activity)
Dynamic Storage Type							✓
No use of eletric Force	✓	✓	✗	✓	✓	✓	✓
Crushability/Stability	✗ (Crushability of the lower loads)				✗ (Stability calculations every time there´s a change)		
Specific configurations	✗ (Rows spaced sufficiently apart, 100 mm between each row; 50mm gap between items in same row)					✗ (Narrower aisles, usually 1.8m or less)	
Retrieval Policy	✗ (LIFO)	✗ (LIFO)	✗ (FIFO)	✗ (LIFO)	✓ (FIFO/LIFO)	✓ (FIFO/LIFO)	✗ (FIFO)
SKU Arrangement	✗ (Fewer SKUs)	✗ (Only one SKU per DIN)					
Speed		✗ (Low)		✗ (Need to be Controlled)			
Equipment Specialization						✗	
Manpower						✗	

characteristics of the real system being studied, over time [58], [59], [60], [61]. 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 authentic systems. The level of congruence between the real system and the model is determined taking into account its objectives and the simplifications in the design [62]. Simulators can be used to represent both existing and hypothetical systems [63], [58].

Simulation allows users to create a representative model of reality, even if approximate, by experimenting with different scenarios with different inputs without constraining or disturbing the functioning of the real system. Before a system is developed or changed, it becomes possible to detect bottlenecks, difficulties, and some design flaws. It also allows a wide range of alternative hypotheses and different operating principles. This is all possible before committing resources to a project, evaluating and comparing options and their viability [60], [64]. For all the factors mentioned, simulation is a method to validate models regarding warehouse operations [65], [66]. Simulation's downside consists of being very time-consuming to run several scenarios, undue reliance on results, data needed for the system might not exist or is too expensive to obtain, does not guarantee the best choice but simply a decent option depending on the criteria given, and the amount of time available before judgments must be made is insufficient for worthwhile research. Therefore, all the weights must be measured in the balance to determine the feasibility of a simulation study, and whether it is the best validation option for the project at hand [60], [64].

3.4.2 Cost-Benefit Analysis

A Cost-Benefit Analysis (CBA) 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 [67]. 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 [68]. Essentially, a CBA is a method of determining what a society's preferences are. When one of a set of alternatives emerges as the preferred one, CBA should convey to the decision-maker which option is the most socially desirable [69].

Before continuing with the focus on CBA, it is important to make a comparison with what decision analysis is. The keyword in this terminology is analysis, which refers to the need to break something larger into smaller elements, using a ”divide and conquer” approach [70]. Decision analysis is defined as a formal method that integrates results so that a plan of action can be tentatively decided upon after each smaller problem has been addressed separately [70], [71].

A CBA is the most comprehensive economic evaluation [68], [72]. This type of analysis assumes the personal values of individuals, quantitatively, for example, how much they are willing to pay for a certain service, or for covering an increased risk, always using a preferred approach given by the observer in question. All methods have their drawbacks, with the most successful method being through the use of a preferred approach. However, this type of process still has some problems with its implementation. At the time of an economic evaluation, the most theoretically sound and complete method for an evaluation followed by decision-making in a project is a CBA. The main difference between CBA and other possible existing 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. The field of applications of a CBA is very broad and can be used for various sectors and industries. For instance, tactics such as cost-effectiveness and cost-utility analyses fail to deliver the same process value because inputs and outputs are measured in different units. By assigning these monetary values to outcomes, it is possible to determine whether a particular procedure offers an overall net gain to society meaning that total benefits exceed total costs [68], [72].

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 [73]. 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, in figure B.14 at the Appendix section B, it is represented how ROI can be measured throughout a logistic operation. 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 higher than zero, or not, otherwise.

Another important indicator to measure a project´ 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 [74], [73]. The general formula to obtain this indicator is: PP = Net investment/Average annual operating cash flow.

3.5 Summary of Chapter 3

This chapter was dedicated to reviewing the main concepts involved in warehouses, reflecting how this storage point fits perfectly into a supply network and what its main functions and interactions with its connecting nodes are. In the retail industry, in order to keep up with the market, it is necessary to provide excellent service levels at low cost (to remain competitive), whilst at the same time providing a wide range of items also at low prices. In the warehouse management segment, a distinction is made between the two types of warehouse that exist, and it is also specified which challenges they face. General ideas on warehouse layout were provided, possible typologies of structures for the storage of large appliances were analyzed contemplating their pros and cons. An investigation was carried out on the value of simulation in evaluating solutions. It is concluded that simulation seems to be the most appropriate method to study complex systems with complex variables. In the state of the art is essential for understanding what exists in the literature, and which knowledge bases could support a methodological development, as well as a proposal to optimize the space defined for Worten case study.

4. Methodology, Data Collection and Analyzes

The present chapter, chapter 4, results in seven sections. The first one is the definition of the thesis methodology as well as its detailed explanation. The defined methodology, presented in the first section was based on the literature review made in the previous chapter and discussed with the Flows Engineering team at Worten. From section 4.2 forward a more practical component of the Master's Dissertation is addressed. The main objective of the data collection sections is to introduce the reader to the company's reality regarding the volumes and quantities of products under consideration for the change under study within the warehouse, providing in a first phase the collection of this information followed by an analysis and interpretation. These being said, the second section is an explanation of the filters used for the information in the following chapters, as well as where all this data was extracted from. The following sections aims to pursue the natural flow of a big-sized appliance within the warehouse, from reception to storage and finally to expedition. Therefore, the sections covered will be Inbound (section 4.3), Storage (section 4.4), and Outbound (section 4.5). The sixth section is dedicated to products rotation, intended as a consolidation of the analyses made in previous sections about inbound and outbound. These analysis will provide essential information for all the studies that will be performed in the forthcoming chapters. The chapter culminates with a brief summary of what was discussed.

4.1 Methodology

A scheme of the proposed methodology is shown in figure 4.1, accompanied by validation tools. It is important to note that this methodology arose from a summary of some of the articles studied in Chapter 3, mainly [65], [18]. This step by step approach is intended to be followed in the future dissertation, in order to achieve the objective of the work, designing a structure that can meet all the necessary requirements of the company.

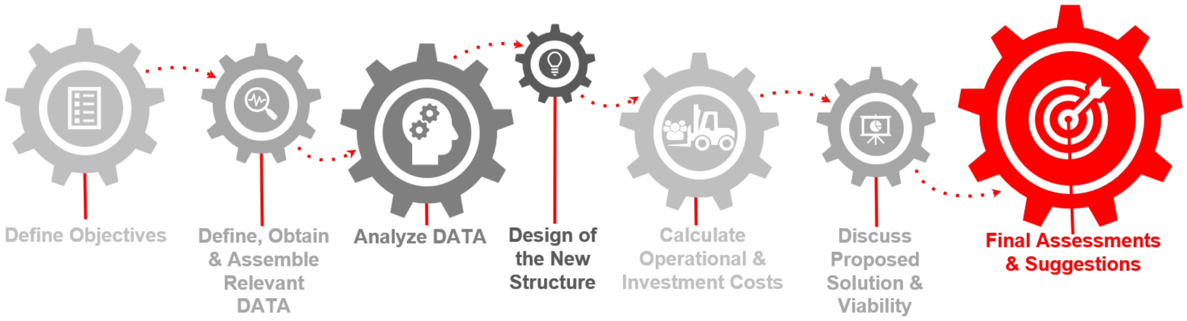


Figure 4.1: Methodology to Develop the Design of a Structure in a Warehouse

The presented methodology consists in seven steps:

1. **Define System Requirements and Design Constraints:** Recognition of the areas' needs, consolidating with the project objectives. Main objectives and intermediate milestones consist in the storage of big-sized appliances, space needs and inventory levels.
2. **Define, Obtain and Assemble Relevant DATA:** This is the phase of the project concerning the collection of information from the universe present in the cloud. With the objectives established in the previous step, it is now possible to establish which data and information are necessary for the execution of project studies. These data will be taken from the WMS system by running queries in Structured Query Language (SQL), in a program called *ORACLE SQL DEVELOPER*.
3. **Analyze DATA:** Next, it is necessary to process the data collected previously. Here all product volumes, inbound, storage, and outbound, will be studied in order to understand what the current warehouse capacity is.
4. **Design of the New Structure:** In the development phase itself and keeping in mind all the possibilities researched in chapter 3, a solution should be reached, discussed and designed in terms of operational flows and functionality. At this thesis stage, all details should be provided. Necessary tool(s) for decision support should be developed.
5. **Calculate Operational and Investment Costs:** At this point all costs relating to the resources needed and involved in the realization of the structure should be provided. These costs include equipment needs for operations and product handling (manpower). The costs for the implementation of the structure will be calculated, with the help of suppliers. The investment costs will be added to the operational costs in order to be able to assign a final price for the idealized solution.
6. **Discuss Proposed Solution and Viability:** In this step, comparisons will be made between the system as is and the new structural idea, containing both empirical factors, i.e. pros and cons of the structural solution, as well as a trade-off regarding its costs and achievements for Worten. Here a financial viability analysis should also be performed.
7. **Final Assessments and Suggestions:** In this last stage, it is presented the final suggestion of the dissertation is made, whether or not to proceed with the implementation of the structure. It is also discussed whether it can meet the needs of the company and the business.

4.2 Data Collection

In the development of the project and in the constant search for information, it became clear that the best way to approach and analyze the problem of storing big-sized appliances in the warehouse, was to perform *a priori* study, that allowed to point out which categories are effectively stored in the area 701 solo area. This was taken as the starting point of every reasoning.

This study was carried out for the year 2021, and for the ten categories 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 justifications, their products had not been effectively stored in the area under study. This allows to point out that in a warehouse of this operative size, often what is in the system does not correspond to reality, and vice versa.

The ten categories found in the system were: 5101, 5102, 5103, 5104, 5105, 5106, 5108, 5110, 5301, 6102. Of these, the categories, 5101, 5110, 5301, 6102 were excluded for the following reasons:

- 5101: This category is called water acclimatization. Within it are products such as heat pumps and water heaters. The water heaters are not stored in this area but in conventional racks. The heat pumps, despite being stored in the solo area, have a very high turnover factor, meaning that when a heat pump is received, it practically always has a purchase order associated with it, causing this type of product to be stored for less than 24 hours in the warehouse in most cases. If they do not have a purchase order, not considering this subcategory does not present a problem, since as a rule, the number of stored units in this subcategory is around 1 or 2 at most. Adding also the fact that this last typology of products has no stacking factor (which means that they cannot be stacked in high), eliminating the need to study further this subcategory and main category.
- 5110: This category is related to solar energy products. These types of products, such as solar panels and related parts, are not stored in this area. This means that currently the category is not well defined within the information system.
- 5301: This category corresponds to televisions. This also consists in misclassification in the system, because televisions are only stored in conventional or gravity flow racks, depending on their size in terms of inches. For more inches, the gravity flow racking system is used, and for the small, remaining ones in conventional racks.
- 6102: It is intended for the category of fitness products, such as treadmills, bicycles, and others, which are also stored in conventional racks. This is again a system parameterization error.

So, to conclude this reasoning, 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**[1]. To complement, the final range of categories under study represent over 99% of the products stored in 701 solo area.

Possible differences in terms of quantities that will be analyzed in the next section (section 4.3), is due to the fact that, in the system, the products that are received in the inbound flow, do not have *a priori* segmentation within the entire zone relative to the 701, so it is not possible to distinguish which are the total quantities stored in this area. In a way, it also becomes relevant to add as a reference the total volume of quantities, because in the future it may be felt the need to store in the space under study,

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[1] The names of the categories have been kept in Portuguese in order to ensure consistency between the terms presented, taken directly from the system and referenced throughout the text.

other categories of products.

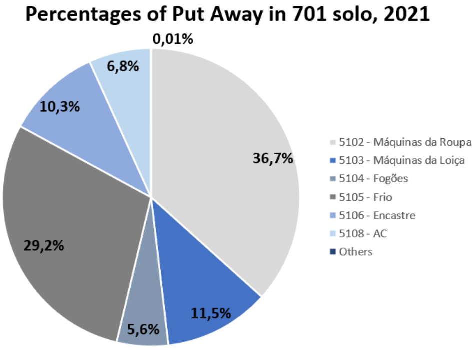

Figure 4.2: Percentage of Put Away by Category in 701, 2021

It is important to mention that all the data presented was taken from the internal information system of Worten by running queries in SQL, in a program called *ORACLE SQL DEVELOPER*. In order to filter all the information collected, the *Microsoft Excel* was used.

4.3 Inbound

Following the journey of a big-sized appliance in the company's heart of operation warehouse, the first step is when the reception of products occurs. A product that is received may originate from two different upstream flows: Supplier Brand (MF) or White Brand (MP).

The purchase and monitoring of these products from both flows is the responsibility of Worten's Stock Team. One of the tasks of this team consists in, after receiving the sales forecast, provided by the Worten Commercial Team, to proceed with the purchase of products in accordance with the estimated figures. These estimates[2] are determined in order to meet demand, translating the monetary units into product units. The stock teams of both flows also need to build their own forecasts of the warehouse occupancy, in order to be able to ensure that all received units can be stored, never sending trucks backwards, nor exceeding the warehouse capacity. The forecast for the upstream MF flow is for a 60-day period, while the forecast for the MP flow is for a 6-month period.

It is also important to better understand why the time horizon in terms of forecasts varies between both upstream flows. This difference comes from the fact that all containers coming from the MP upstream flow, have it´s origin in China. This path adds to the equation many variables and possible bottlenecks, which all supply chains face nowadays. Examples of these bottlenecks are stock-outs due to the increasing difficulties in the production of electronic components in the largest producer in the sector (China), adding the impediments, bureaucracies causing prolonged waits both in the transport to Portugal and

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[2] Graphs relating to this information will not be shown in this master thesis, as it is a highly confidential information inside and outside the company, to which only key managers have access.

in the customs clearance of the products at the port. Although the MF flow is also affected to some extent by all these variables, the fact that the route is shorter facilitates and reduces both the impact of these bottlenecks and their speed of resolution. Many of the suppliers related to the last upstream flow, supply Worten's warehouse from their factories based in Europe. Usually, the shorter the path, the fewer constraints the products have to pass along the way, making it easier for them to arrive at their final destination with fewer occurrences.

Exploring the equation factors mentioned previously, with the onset of a pandemic crisis, there has been a sudden paradigm shift, causing supply chains in all sectors to be constrained, failing to meet the estimated delivery schedules. Added to this was the existence of abnormal levels of peak consumption in many product categories. Since the beginning of the pandemic, Worten has undergone some structural changes concerning its supply chain, which ended up inserting even more effort load, increased need for improvements and developments in the central operations warehouse based in Portugal. Some of these changes included the closure of practically all physical stores in Spain (with the exception of one), as well as their warehouse in the country, making all products to be shipped from a single warehouse (Portugal), and investing increasingly on the maturation of the online channel. This factor impacts considerably the level of fulfillment and the entire supply chain of the company. All of these factors contribute to a significant variation that may not be representative of the normal activity of the company.

In order to further characterize the inbound, it is necessary to observe what quantities are received at the company's central warehouse, giving a more real perception of the volume (in units) of products that enter and then need to be stored. The graphs in figures 4.3 and 4.4, represent quantities received relatively to the flow of 701, big-sized appliances. The company in terms of reception does not have control over what goes from the entry docks to each area of the warehouse, this segmentation is done a posteriori.

The graph 4.3, show the quantity received in 2021. The lines in red represent the total quantities received, including all product categories relating to the internal flow 701, while the bars include only the values of the restricted range[3] of categories within this flow, selected previously in section 4.2. The fact that only a few categories are represented, filtering the observation of only a specific range of products, approximates the entire analysis to the reality for that particular zone.

The graph 4.4, shows, within the category selection, which quantities are relative to the MP and MF flows. The bars in the graph represent the year 2020, with the red color relating to MP and the gray color to MF. The same reasoning is done for the line segments connecting the various points, characterizing the year 2021. Again the red line is relative to the MP and the gray line to the MF. These quantities for the selected categories match those represented in the 4.3 graph by the vertical bars.

Consolidating graph 4.3 and historical data from 2020, and making a first overview of the values pre-

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[3] Remember that this range is the one defined in section 4.2, which represents 99% of the categories stored in the 701 solo area and not the entire 701 area, this last one also including all the other warehouse structures.

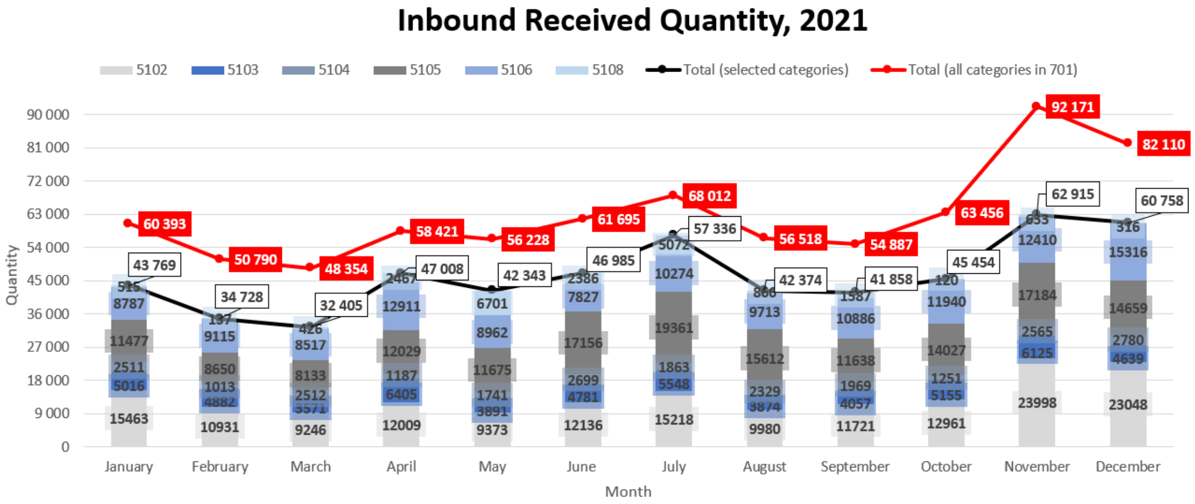

Figure 4.3: Quantity received in 701 flow regarding the year of 2021

Table 4.1: Growth Percentages in the Inbound, relative to the years 2021/2020

Months	**Growth 2021/2020 %**
January	-2%
February	-9%
March	3%
April	98%
May	-6%
June	-8%
July	4%
August	3%
September	5%
October	-13%
November	23%
December	46%

sented, a growth analysis was executed, see table 4.1. Note that this next analysis is relative to the categories selected, see section 4.2 and not the total quantities in 701. Thus, in the months of January, February, May, June and October, there was a decrease in this growth, however, never less than 13% (October) of the quantities received in the homologous periods. The months of March, April, July, August, September, November and December, there was always an increase in the quantities received in 2021. In the month of April, the warehouse almost double, 98%, the amount of the received merchandise, and in the month of December an increase of 46% was calculated. These are the two biggest months in reception registered in the past year.

Making a more general analysis of the selected quantities, based on graph 4.4, and using the table 4.2, that results from the sum of all quantity received in each year, and the respective growth percentage of each upstream flow. It can be observed that in 2020, the warehouse received 515 051 units, and 557

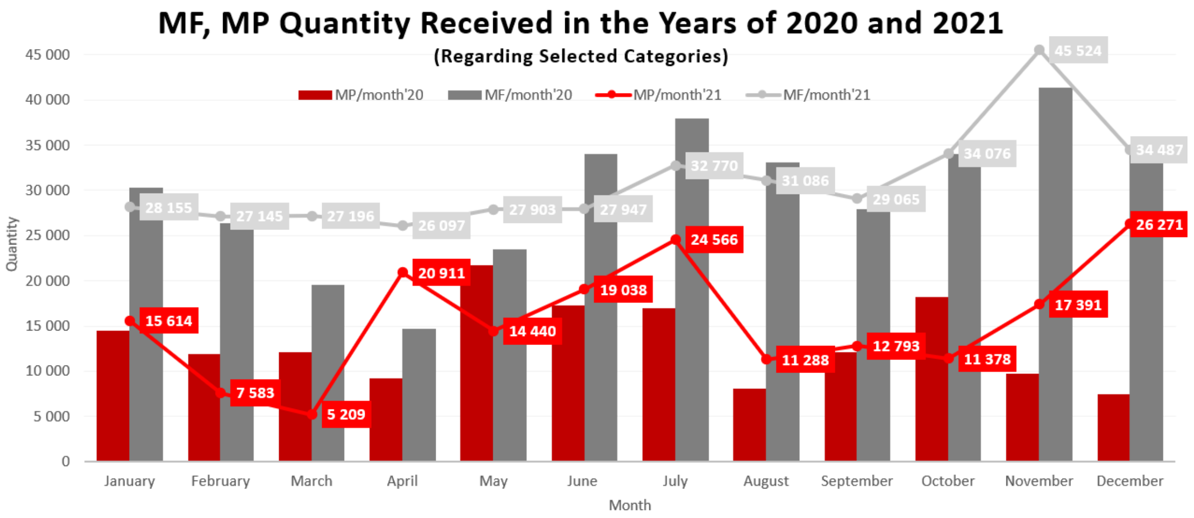

Figure 4.4: Total quantity received in 701 flow regarding the years of 2020 and 2021 for upstream flow

Table 4.2: Total Quantity Annually and Growth Percentages in the Inbound regarding each Upstream flow MF and MP, in years 2021/2020

	2020	**2021**	**Growth between 2021/2020 %**
MF	356 591	371 451	4%
MP	158 460	186 482	8%
Total	515 051	557 933	8%

933 units in 2021, showing an increase of 8%.

If a filter is applied relatively to the growth between the years under analysis with reference to upstream flows, observing still table 4.2, it is also possible to verify that the MF grew by about 4% and the MP by 18%.

In 2020, the company suffered an abrupt drop in units received when the pandemic crisis started in Portugal, visible significantly in the month of April, 2020. It is also possible to observe that in the two years under analysis, the peak in quantities received was in November, the month corresponding to the biggest promotion campaign of the year, Black Friday. Due to the substantial increase in sales, it is also necessary to increase the stock in order to meet demand, and to avoid losing sales due to the occurrence of stock outs. In the graph 4.4, with the product flow distinction, it can be seen that the number of quantities coming from MF is higher when compared with MP. In the month under observation (November), for 2021, the value in units of MF was approximately 2.6 times higher than regarding MP.

In general, it can be seen from the graphical trends that the future forecasts for both business areas tend for the continued growth. The company's objective is to continue to grow, expanding into other channels and types of business, in order to be the absolute leader in sales in Portugal, selling a wide range of products, and look for international opportunities.

The graph in figure 4.5 shows the relationship between the warehouse sizing and what was actually received, as well as its accuracy throughout the year of 2021, for the 701 flow. This warehouse sizing/capacity varies on a weekly basis. Depending on the free space at each evaluation and also consolidating receptions and sales forecasts from the expedition point of view.

Let's take an example for this ratio relatively to the first week of the year 2021, week 1 (the calculation is done in units):

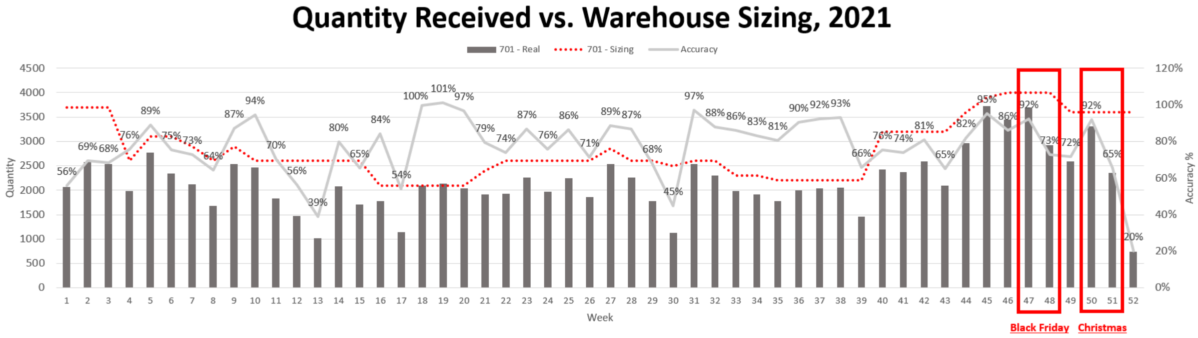

Figure 4.5: 701 Reception Quantity vs. Warehouse Sizing, 2021

For the study of this master thesis it was only possible to collect some data from 2020, which forces that forthcoming sections and chapters include data only relative to 2021. This is because the company only began to systematize its information network from the year 2020 ahead, which makes it impossible to obtain data relative to previous years.

The Flow Engineering Team is also responsible for consolidating information about the delivery of goods on a daily basis, according to the availability of containers in the port. According to this availability, it is then possible to program the delivery of the products, even though they are cleared to go on their way, it is necessary to guarantee that the warehouse has the necessary both handling and storage capacity. If it is not possible to store them, they have to be forwarded to the warehouse where Worten rents extra space for big-sized products. If by chance, this warehouse also no longer has space to accommodate these items, it is necessary to keep the containers at the port paying extra and very high fees due to the lack of space in both warehouses.

4.4 Storage

Already containing the quantities that were received, serving as a volume input for the 701 flow, it was necessary to further filter the information in order to have a visualization of what was actually stored in the area to be intervened, 701 solo. Therefore, graph 4.6 presents these quantities within the range of selected categories. It is possible to analyze that the portion related to MP is 36% and MF is 64%, for the

Table 4.3: Quantity Stored on Average, Minimum and Maximum in the year of 2021, in a Month

	Stock In a Month regarding Daily Values		
Months	**Average**	**Max**	**Min**
January	**26 133**	29 636	**23 897**
February	31 080	33 442	28 481
March	30 149	31 928	27 354
April	29 865	31 591	27 188
May	30 904	33 238	28 328
June	27 835	29 229	26 185
July	29 274	31 006	25 684
August	27 401	29 162	25 214
September	28 147	30 091	25 864
October	29 986	33 186	26 794
November	**32 053**	**35 089**	29 172
December	30 398	32 458	26 669

year of 2021. It was defined by the warehouse management that a daily limit space of 2200 m^2, can be used for MP products in the area to be intervened, the rest is reserved for MF. It is also possible to see that the months in which more products were stored in the area was in November and May. This high storage value is due to the increase in the arrival of products before the summer to meet the expected boost in requests during the season, as well as in defined campaigns throughout the year, as previously explained.

The graph, 4.6, represents in black, the average stock stored in this area with daily readings for each month (both upstream flows), see also table 4.3, first column. This means that November was the month in which, on average, more products with this destination were daily stored in the warehouse. Also giving a clear idea that, on average, the daily quantities stored are always between 26 133 and 32 053 units. On an yearly basis, evaluating daily values, the range was between 23 897 and 35 089 units (not shown in the graph). These values are marked in bold in table 4.3: the average column shows the minimum and maximum values. In the column for minimum values, the minimum quantity stored in 2021 is in bold, and the same reasoning was done for the column of maximum values. These values are relative to the daily stock stored during all months of the year in the study area. This shows the fluctuation of the annual values relative to the average, considering minimum and maximum units.

A few years ago, the company conducted a detailed analysis of the entire range of products stored in the 701 solo area. From this analysis, considering all product categories and subcategories, as well as both upstream flows and also the m^2 of each location adding the correspondent aisles, it came to the conclusion that for every 1 000m^2 of area, it could be stored, on average, about 4 207 units. In this study, it was deduced, that 37% of the space is inefficient, as it corresponds not to useful storage area, but to circulation aisles. The variables used to consolidate the entire range and categories were the variables of the products' base area (length*width), and their respective stacking factor. However, as time went by, the warehouse space team understood that this value always overestimated the space needed, meaning that, in many circumstances, the estimated amount of products being possible to store, then, in reality, didn't fit in the area and had to be sent to the company's rented warehouse. This growing number of movements increases the company's costs for the handling of products. Thus, a new analysis was then performed, considering all the previous variables, and it was deduced that a value closer to reality that underestimates the space, would be to store about 3 400 units in each 1 000m^2 of area. This is then the daily target, for an effective put away of products on the solo, when scheduling containers for the warehouse.

So, the formula used roughly, by the space team when scheduling containers is:

$$SpaceRequirements(m^2) = \frac{NumberofUnitstoReceive}{\frac{3400units}{1000(m^2)}} \tag{4.1}$$

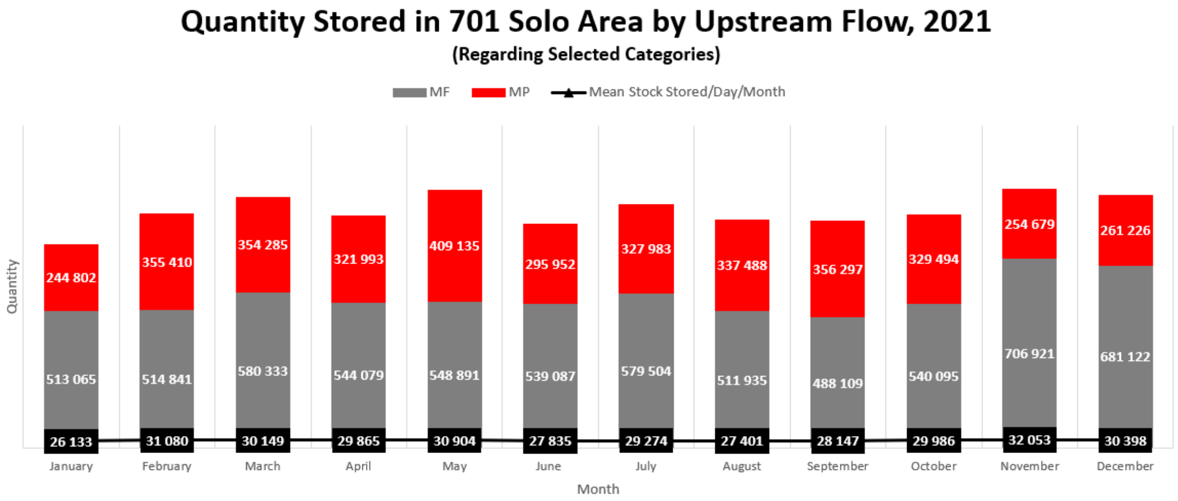

Figure 4.6: Quantity Stored in 701 Solo Area by Upstream Flow and Mean Quantity Stock/Day/Month, in 2021

The graph 4.7, represents the stored quantity for each category in 2021 in the area under analysis. It can be seen that the category with highest stored units is 5102, referring to washing machines, and then 5105, which is the cold category. The greatest variation in storage throughout the year is category 5108, related to air conditioners, directly linked to seasonality. This is due to the growing demand for this type of equipment, when the weather gets colder, in winter, and warmer in summer. The remaining ones are practically constant and with little variation throughout the year.

In section 4.6 a detailed study will be dedicated to the rotation of these categories within the warehouse.

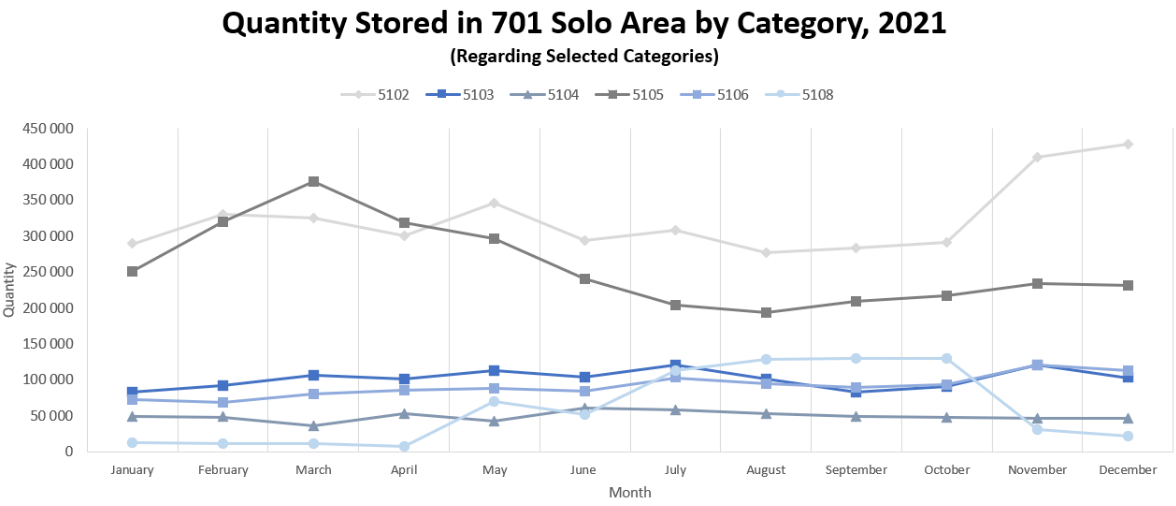

Figure 4.7: Quantity Stored in 701 Solo Area by Category, in 2021

4.5 Outbound

Going into the outbound area and the respective shipping flows, as explained in Chapter 2, the products leaving the warehouse can go through two distinct routes. On the one hand, via PBS, when they are to be delivered to stores for replenishment, and on the other hand via SCED, which is related to delivery of big-sized appliances products to the customer's home. Therefore, to correctly evaluate the outbound flows, it is necessary to analyze both the quantities shipped, either for delivery to the store or for delivery to the final customer.

The graphs in figures 4.8 and 4.9 represent the quantities shipped via PBS and SCED, respectively.

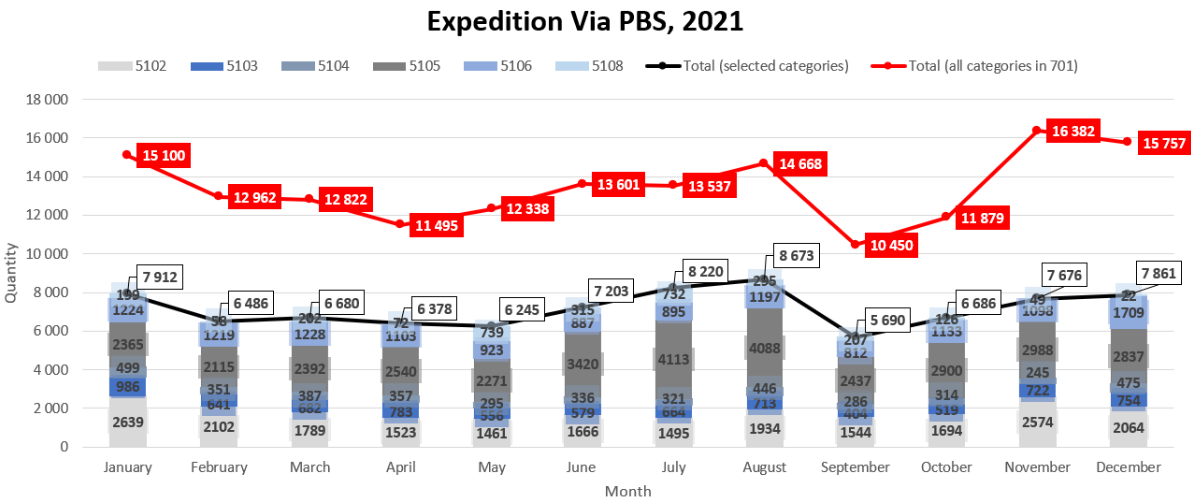

Figure 4.8: Expedition Quantity Via PBS per Category Considered and Regarding Total, 2021

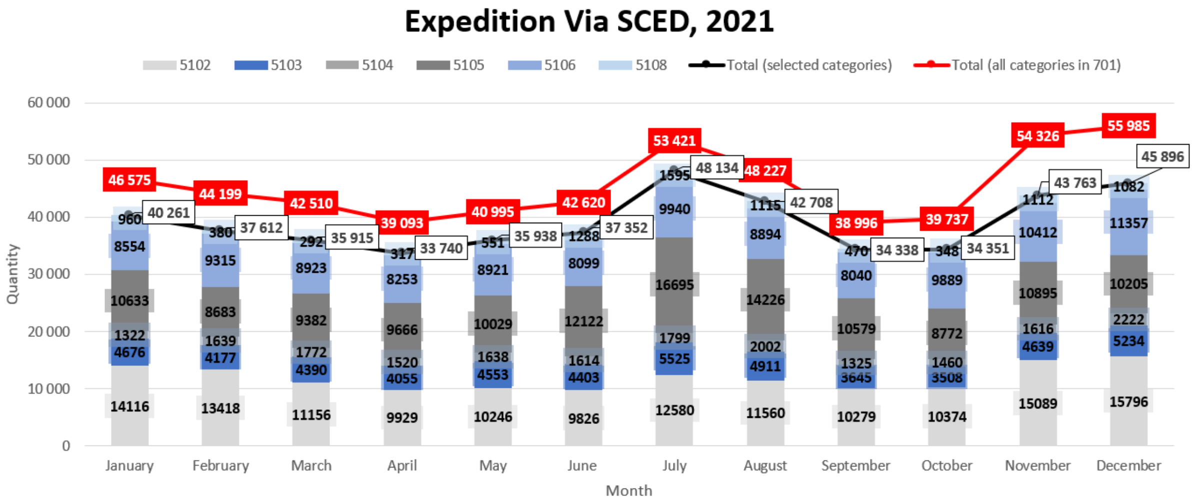

Figure 4.9: Expedition Quantity Via SCED per Category Considered and Regarding Total, 2021

Looking at both graphs, it is possible to see that the number of outbound shipments via SCED is much higher then the number of in-store deliveries, during the entire year under analysis. Throughout the SCED flow represents, on average, 77% of the total of item 701 shipped, with PBS having a complementary weight of 23%. In more detail it can be concluded that in relation only the categories under study that are stored in the solo area (represented in vertical bars), on average, in the year under analysis, the SCED accounts for 85% of the expeditions, leaving 15% for the PBS flow.

Another detail that can be observed and supports the previous statement, is that in the PBS graph 4.8, there is a considerable difference between the quantities of the categories considered and the total of the 701, which in the SCED, 4.9, is no longer the case. That is, there is a great approximation between the quantities shipped from the analyzed categories and the total shipped via SCED. This difference is explained by the fact that a PBS request does not necessarily have to come from the solo area, even if it is a 701 request. In other words, it could be induction hobs, outlet items, smaller air conditioners, among many others that are not picked and stored in this area but in rack structures. This does not happen with SCED. The only item that follows the SCED flow and is not stored on the floor in a block stacking system, are the televisions that are in gravity flow racks (the larger ones, with more inches) and conventional racks (the smaller ones, with less inches).

By now consolidating the values of both flows, the following graph is obtained, 4.10, which facilitates a more global analysis.

The total quantities shipped monthly related to the categories represented in the vertical bars show more or less constant values, between 40 028 (September) and 56 354 (July) units, as can be seen in graph 4.10.

The top main months with the highest number of sales of these items and consequently their shipment,

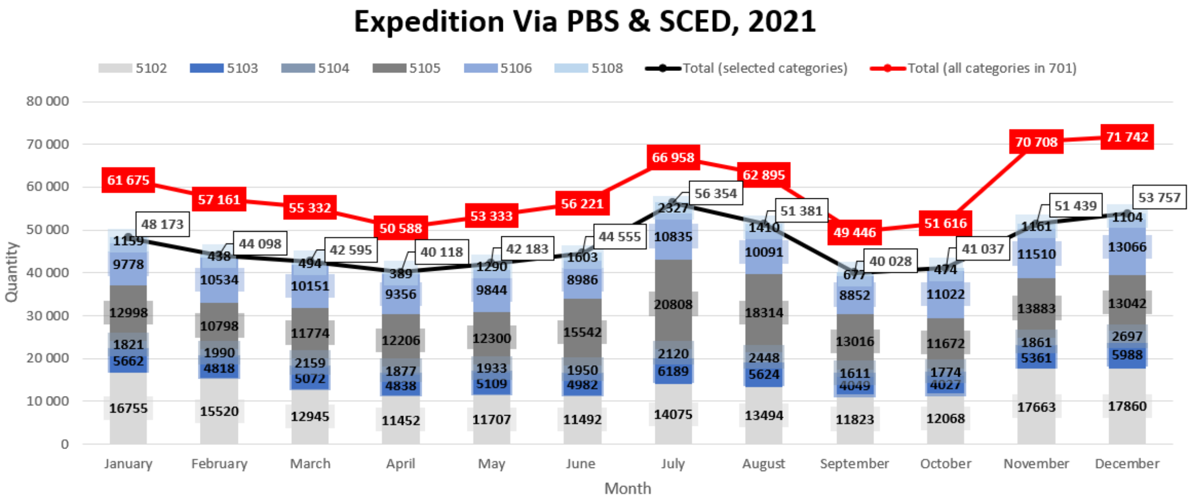

Figure 4.10: Outbound Quantity (PBS and SCED) per Category Considered and Regarding Total, 2021

are as previously mentioned in the inbound section 4.3, the months related to the summer season and also those related to Black Friday and Christmas, which are exactly in line with what is shown in graph, 4.10. The months with the highest values of shipped units were December, 71 742 units, followed by November, 70 708 units, and finally July, 66 958 units. The months of January and August also showed values above average, 61 675 and 62 895 units, respectively. It is also important to point out that the fact that January also presented a considerable value of shipped quantities is due to the compensation of stock that was sold online and needs to be sent to be picked up by the final costumers in stores. By this sale being made in the previous peak months, and adding the fact that many orders placed may only be delivered at the beginning of the year, due to the holiday disturbances, delaying all the transport and handling that takes place at the end of every year. This outbound analysis is important to be able to determine which categories have the highest and lowest outputs in a given period of time, which in this case will always be relative to the year 2021.

4.6 Products Rotation

This section essentially aims to understand which categories generate the greatest movement in and out in the warehouse, in order to look for a pattern of product rotation in the warehouse. The following explanation will be given in terms of product rotations, as there is not as a rule for space allocation per category, it all depends on the free space in terms of locations at the time of storage.

Looking at the graphs in figures 4.3 and 4.10 regarding inbound and outbound respectively and considering only the vertical bars, for the 6 categories under study, the following conclusions can be drawn. The 4.11 graph was built to understanding, in the sense that it is possible to observe what were the quantities in each month within each category that entered and left the warehouse.

Exploring the graph 4.11, the reader can see that the most requested categories in terms of sales and subsequently in terms of storage are 5102 first, then 5105, and finally 5106. These categories are the ones that come in and out of the warehouse the most, showing the highest turnover. The ones with the lowest turnover quantities are categories 5103, then 5104, and lastly 5108. However, it is also possible to see, 4.11, that the balance at the end of a year of operation, meaning that entries and exits have approximate values for practically all the categories and respective product ranges, with the exception of 5108, which presents a more accentuated difference. This variation may be accentuated by the fact that 5108 (ar condicionado), is a very seasonal product category.

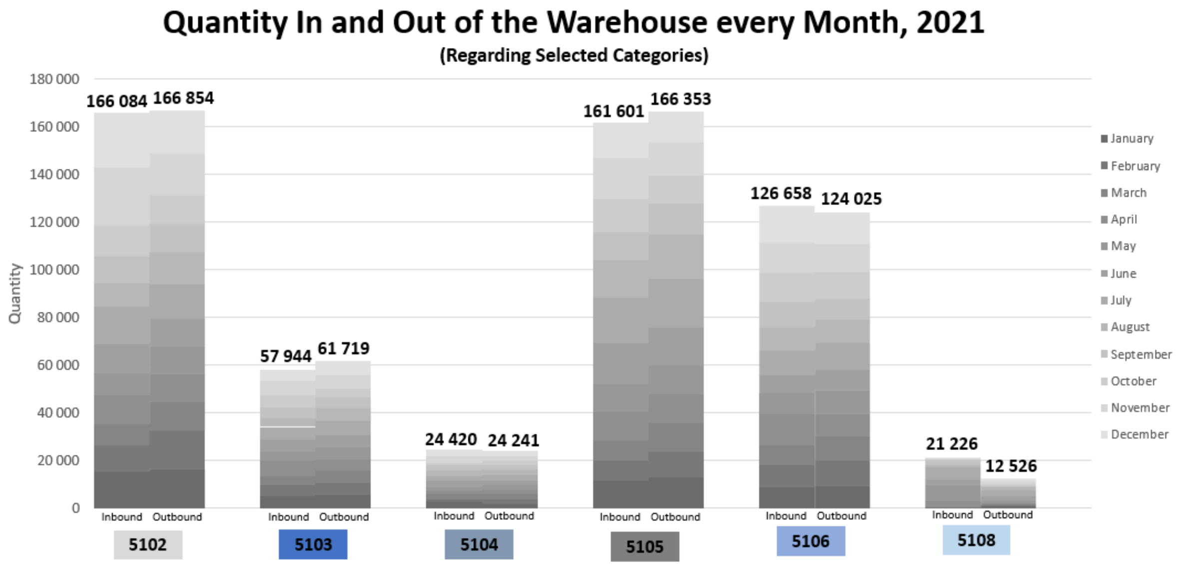

Figure 4.11: Quantity In and Out of the Warehouse Every Month, 2021

4.7 Summary of Chapter 4

Chapter 5, with less theoretical and bibliographical content and more focused on the analysis and verification of important facts, data collection considerations and focusing on the volumes of inputs and outputs of the Worten´s central operations warehouse were studied. This chapter, also shows the values in terms of quantities stored in relation to the area of the 701 solo. In these storage quantities, it was possible to observe that the upstream flow of MP, has shown a growing expression in the company's business. Some current situations regarding the constraints of operations were also discussed. Sources of cost and trade-offs that should be considered for discussion in future chapters were also presented.

It is also clearly visible that the fact that today it is not possible nowadays to account for the entire volume, influencing directly, both the collection capacity and the respective effort loads, as well as the space requirements in terms of m^2 of storage.

5. Design Development

The chapter 5 is the most practical chapter of the entire thesis. It is divided into five sections. The first part, section 5.1 includes a detailed spatial description of the current system that the company has in the space to intervene. In the following part, section 5.2 starts the study applied to the structure suggested for implementation. This section is divided into two subsections. The first discusses how the proposed solution was reached, and the second shows how the daily operation of this space will be executed.

Passing on to section 5.3, the main focus is related to all the analyses performed to evaluate the solution presented and to understand what gains were obtained with the suggested investment in terms of space. Two analyses will be made to the problem, and in the second one, an operational simulator was developed from scratch by the author in *Excel* to obtain several scenarios.

The penultimate section, section 5.4, is dedicated to the evaluation of operational and investment costs, in the first phase for the current scenario and the second phase for the project at hand.

To conclude, a summary of the chapter is made that will allow the reader to consolidate the most important topics and information, in helicopter mode, section 5.5.

5.1 Detailed Evaluation of the As Is System

This first section is dedicated to the most detailed description possible of the study area as well as some good practices that need to be taken into account when approaching a project with operational purposes. The action area of the project has already been described and explained in Chapter 2, as well as all its surroundings in a more macro way. The selected area is a rectangle which will be the destination of the structure's construction because based on all the bibliographical review made in Chapter 3, it was possible to verify that rectangular and symmetric layouts reduce operational efficiencies and also facilitates all the handling of products. This is why the SM part was excluded.

Therefore, some points regarding the early concession are important to take into consideration:

- This area of the warehouse is closer to the entry docks because the shipping flow via SCED uses these lines as its shipping lines.
- It is stipulated as a good practice not to start labelling areas, aisles, and locations, with the first letter or number to be easier to adapt in the future, should the need be felt. An example of this is the first corridor starts with the name GB instead of GA.
- The corridors where the layout of an area begins, as they are dividing corridors between different areas of the warehouse, have to be wider due to their need for constant passage.
- It is very important that there are no supporting pillars in the middle of corridors.
- The distance between the reception stages and the storage area must be large and proportional to the input flow (the higher the flow, the greater the distance).

- Avoid as much as possible paint lines on the warehouse floor, as these are difficult to remove, and thus the layout can become flexible. Plastic tape is also difficult to remove. This is especially important in staging areas because of their constant need to be updated according to flows.
- Always sizes the buffer locations according to the operating volumes.
- Arrangement of bins to allow for a clean warehouse, and no leftover materials in passing is vital to the smooth running of the operation.
- Ensure that people always have enough space to move around and that emergency exits are always unobstructed.

Figure 5.1 shows a more technical plan for this area. The values are in mm.

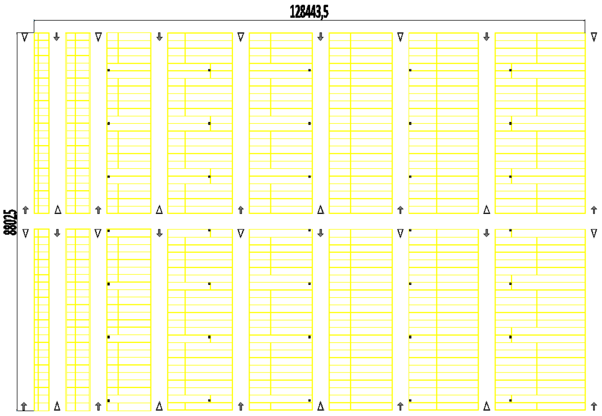

Figure 5.1: Warehouse Blueprint of the Area 701 Solo to be intervened *(measurements in mm)*

Other data regarding this area is now presented:

- **Ceiling Height** = 12 m at the highest point, 11 m at the lowest point (that is, using the lowest point of the beam)
- **Number of Supporting Pillars** = 35
- **Length** = 128.54 m
- **Width** = 88.03 m
- **Width of Vertical Aisles** = 3.8 m
- **Width of Horizontal Aisles** = 3.58 m
- **Area** = 11 315.04 m^2
- **Aisles Area** = 2 801.65 m^2, about 25% of the area (remaining 8 513.39 m^2 for usable space)
- **Useful Area (product locations)** = 7 640.84[1] m^2, corresponding to 724 locations, and 68% of the entire 701 solo area (excluding always the SM section)

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[1] Every data regarding active locations varies over time, due to blockage for logistic services and/or quality control maintenance. One should bear in mind that all solo locations are active locations if the picking can be performed in that location. This data was collected in the 1st of March.

- **Total Number of Picking Locations** = 839, however in theory if none of the locations were blocked by some of the reasons already mentioned, there would be 945 locations in the solo area
- **Current Expected Location Efficiency** = 56% (this is the maximum expected value for space efficiency, considering aimed quantity per 1 000 m^2)

All the information in this sub-chapter is important for the design of the new structure and all its functionality, from the equipment to be used, to its construction and design of the operation, to be carried later on.

5.2 Design of the New Structure

This section consists of two parts. The first part is about explaining which two structural hypotheses were considered by the company and discussed by the Space and Productivity Team. Of these two hypotheses, only one will be chosen, as it is the one that presents the most advantages to meet Worten's volume needs, in terms of storage of products, at the present moment and for the upcoming needs. The second part of this section consists of the explanation of the system to be addressed, how it will work in operational terms, and what will be the most impacting differences relative to the current system. Here the operational flow charts will be presented in detail.

5.2.1 Pre-selection of the Design

Initially, there were several possible ideas for this area, including the replication of some types of structures that already exist in the warehouse, which were also discussed in Chapter 3 of the literature review. Therefore, after this first brainstorming, two possible outputs resulted for the solo area 701.

The first solution involves a platform, which will function as a mezzanine, making possible to reproduce the current block stacking system in height.

The second solution would be a mixed one, where at ground level there would be a block-stacking system like the currently used, while at a higher level, would be adopted a highly dense and robust storage structure with a push-back system.

However, before proceeding to a more detailed analysis, the space management and productivity team discussed again both options' feasibility. Analyzing and comparing the hypotheses considered, the conclusion was reached that only detailed studies, including the feasibility of investment for the first solution, related to the platform, should be carried out.

The reasons for this decision are now explored. Firstly, the planned push-back structure is a substantial capital investment that the company was not prepared to undertake with its future business prospects.

Secondly, this new structure would be highly dense and robust, affecting all the operational flows of the warehouse and not only those of the area in question, raising issues such as circulation of equipment and ease of adapting the space to possible future changes.

Thirdly, another disadvantage encountered for this type of structural solution was that the products to be stored have different sizes to achieve a set of measures for a lane that would allow the storage of varied items without the significant loss of space. This subject is relative to the storage policies used, because, considering the variability of products that enter the warehouse, it is necessary to maintain a random policy, so that any available lane can be used to store any item, never presenting a waste of free locations that cannot be occupied because they are dedicated to a certain SKU. For the type of products stored in this area, the turnover and the number of SKUs is very high for the number of existing locations, resulting in the impossibility of having a dedicated storage policy.

Quarterly, for this type of push-back system, the products need to be palletized a priori, which goes against the current needs of the products. This would introduce a significant bottleneck to the operation regarding productivity and space inefficiency as it would only be possible to place two or four products on a pallet in the best-case scenario. To eliminate this disadvantage, an adaptation of the ”drawers” was considered, in which a metallic grid would be placed on them, making it possible not to palletize the products. The company was not satisfied with this adaptation due to this similarity being currently used nowadays in one of the conventional rack structures, which did not facilitate the operation at all, from the point of view that many times the products get stuck and it becomes a bigger challenge to handle them without the support of the pallet, and also no supplier was able to supply such a specification. The use of rollers was also ruled out from the start due to several problems encountered in gravity flow rack structures, where the products instead of ”rolling”, as they are very heavy, are also often stuck. In this type of system, due to the high inefficiency of rollers, the items placed currently are always stored on top of pallets, and instead of the products sliding by the action of gravity, it is the pallets, to avoid the setbacks mentioned. Another more technical disadvantage is the fact that with the solutions that are currently present on the market, and with the weight that the structure would have to contain, it was always necessary to have the equipment when letting down a pallet on both sides of the structure to make balance, in order always to guarantee its stability. This inserts an operational bottleneck, adding a need for an increase in the number of workers and equipment required to be used in every activity performed inside the structure.

When researching potential suppliers for this option, no company was found in Portugal capable of taking on a project of this scale in the business area of supplying storage structures. Six suppliers were contacted for this purpose. So, for this project to come to fruition, a supplier in the United Kingdom, *Apex Steel Structures. Ltd* was considered. However, based on experience from other projects, all communication and maintenance of equipment with companies not based in Portugal presents a significant disadvantage and valid reason not to proceed with the project.

As previously mentioned at the beginning of this subsection, and using all the points explained so far as a basis for this choice, the structure that will be addressed for the whole development of this project will be a warehouse platform/mezzanine. A figure giving the similar idea is presented in the appendix section appendix C, figure C.4.

5.2.2 New Structure´s Operational Flows

This subsection will be devoted to explaining the operational functioning after the construction and complete implementation of the dimensioned platform structure.

For such an investment in an operation set up that runs 18 hours a day, 7 days a week, it is required deep analysis of trade-offs between the advantages and disadvantages. These considerations will be analyzed in detail later in chapter 6.

The structure of the platform itself only inserts in the current operation (system as is), the ascent and descent of the products. Now it will be explained the journey of a big-sized appliance since it enters the company's warehouse, from a more operational and process point of view.

In the 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 product. This flow of entries will be the same as the system as is. To recall the process, see figures A.7 and A.8 in the appendix section, appendix A.

In a second phase, with the products, already checked, they wait in the lines to be stored in 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 breakage, and also concerning the productivity of the processes. Thus, the WMS will continue to apply a random and dedicated storage policy, i.e., only one SKU (one reference) is stored per lane. However, does not matter in which one the product is placed. If the lane has a particular SKU or is empty, either the same reference is stored in the first case, or a random one in the second. 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 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 arranges the products in the right locations, performing the put-away activity above the platform. This equipment will always be on top of the platform, because due to its weight, and in order not to be necessary to build a freight elevator that would compromise the layout of this area, it is not possible to lower it, only with the rental of a crane. The counterbalance forklift with clamps for handling such big-sized appliances weighs about 3 tonnes. This operational flow is described at the Appendix section C, C.1.

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 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 at the bottom of the platform. Meaning that there are only active locations in the solo area. On top of the platform, the locations are considered 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, placing the item in the semi-automated order picking trucks. This process ends with placing the products on the shipping lines in front of the entry docks, in the case of the SCED picking. If it is the PBS flow, the products might leave in the PTS area or in the exit docks. Both SCED and PBS flows can be observed at the Appendix section C, C.3 and C.2, respectively.

In a fifth stage the shipping operation is then performed, which is done in the same way as it is nowadays. See figures A.10 and A.9, in the Appendix section C.

A description of any operation that is the same as in the as-is system can be found in detail in Chapter 2 of this master thesis.

The platform will have both inbound and outbound sides and stairs that will allow personnel access to the platform. Will also be implemented a handrail around the perimeter of the platform to ensure security. As well as three gates, called ”endless”, [75], two on the reception side and one on the dispatch side to speed up the movements and make the whole process safer. These gates are revolving, i.e., it is rotated to be open to the placement of the products on top of the platform, and rotated to close, as soon as they are moved with the counterbalance forklift with clamps. A minimum of two operators will be required for bottleneck-free operation on top of the platform. One person will drive the counterbalance forklift with clamps to store the products being dropped off at one of the available gates, and another person will ”lower” or ”raise” the gate when it needs to be used or not. This person will assist with anything that may be required. The equipment needed to place the products on top of the platform will have to be variations of counterbalance forklift models with clamps. Currently, in the warehouse, there are two versions of this model, one that has a height range of 5.80m, and another that can climb up to 8.50m. The equipment that will be placed on top of the platform will be the 5.80m version because it is necessary to ensure that it can circulate on top of the platform without any constraints, as this one is a smaller and lighter version of this vehicle typology. Any one of these two versions can be used operating from the solo area, to place the products in the platform gates.

All operational flows that have changed considering now the construction and implementation of the platform, can be found in appendix section C: C.1, C.2 and C.3.

5.3 Space Analysis

In this section all the analytical parts will be explained, so that it is possible to withdraw as a first output what should be the most advantageous height of the platform, which can optimize the storage of all types of products concerned, either underneath or above the platform. When simulating this value, several variables will be taken into account, namely the maximum filling, both in terms of height and in terms of space concerning the entire floor area. This reasoning will also have to be replicated when storage occurs on top of the structure.

All the analyses were made based on information taken from the company information systems, relative to a script that runs automatically every day and allows WMS to take a photo of what is stored in a detailed way in each location regarding the area of 701 solo.

5.3.1 Analysis I

In the first data processing situation, a simpler analysis was performed to understand how the products behaved concerning their heights and stacking factors, as these are direct inputs for the calculation of the platform height.

Thus, all recorded heights (excluding outliers, clear system errors) within each category, as well as the corresponding quantities, were collected and a mean value of the heights (equation 5.1) was calculated. Then the value of the respective standard deviation of the product heights (equation 5.2) was figured out. The idea is to calculate an average height by default (equation 5.3) and by excess (equation 5.4), using the mathematical function of the standard deviation (equation 5.2) to understand how the height value can vary within each category. The same reasoning was done for the stacking factor, calculating a weighted average with the respective quantities of each number (equation 5.5) as well as the standard deviation (equation 5.6), obtaining a stacking factor also by default (equation 5.7) and by excess (equation 5.8). The conditions are now met to arrive at a weighted total stack height (equation 5.9), as well as by default (equation 5.10) and by excess maximum stack height (equation 5.11). The table 5.1, indicates the name of some acronyms used in the presented formulas, to simplify the expressions. However, all acronyms can be found in the corresponding initial list in this master's thesis.

$$AH = \frac{(PH \times 10^{-2}) \times CQTY}{TotalQTY} \tag{5.1}$$

Table 5.1: Expression Names and Nomenclatures

Nomenclature
Average Height (AH)
Product Height (PH)
Correspondent Quantity (CQTY)
Standard Deviation (STDEV)
Sacking Factor (SH)
Average Stacking Factor (ASH)
Product Pile Height (PPileH)

$$STDEV(PH) = STDEV(AllPHValues) \tag{5.2}$$

$$STDEV(PH)_{Default} = AH - STDEV(PH) \tag{5.3}$$

$$STDEV(PH)_{Excess} = AH + STDEV(PH) \tag{5.4}$$

$$ASH = \frac{SH \times CQTY}{TotalQTY} \tag{5.5}$$

$$STDEV(SH) = STDEV(AllSHValues) \tag{5.6}$$

$$STDEV(SH)_{Default} = ASH - STDEV(AllSHValues) \tag{5.7}$$

$$STDEV(SH)_{Excess} = ASH + STDEV(SH) \tag{5.8}$$

$$PPileH = (AH \times ASH) \times 10^{-2} \tag{5.9}$$

$$PH[STDEV(SH)_{Default}] = STDEV(PH)_{Default}) \times STDEV(SH)_{Default}) \times 10^{-2} \tag{5.10}$$

$$PH[STDEV(SH)_{Excess}] = STDEV(PH)_{Excess}) \times STDEV(SH)_{Excess}) \times 10^{-2} \tag{5.11}$$

It was then possible to conclude that a much more detailed analysis was required as it was not possible to ensure a maximum stack height that could evenly include all categories without waste of space above the structure, see table 5.2. This concern stems from the fact that the useful height both underneath and above the platform has to store the products as efficiently as possible, always complying with their safety coefficients. The categories that stood out the most, showing an excess weighted maximum stack height value quite different from all the others, were 5102, 5105, and 5106 corresponding to Máquina da Loiça, Frio, and Encastre.

Looking again at 5.2, it can be seen that it is not possible to consider a height that could encompass

Table 5.2: Analysis I Outputs

Category	Description	PH vs. SH [m]	PH vs. STDEV(SH) by Default [m]	PH vs. STDEV(SH) by Excess [m]
5102	Máquina Roupa	3,12	1,38	5,09
5103	Máquina Loiça	4,24	2,05	6,93
5104	Fogões	3,76	1,97	5,75
5105	Frio	4,83	1,41	9,81
5106	Encastre	3,93	0,51	10,56
5108	AC	2,61	0,05	5,17

the maximum height of all stacks and every product. Therefore, it is necessary to further granulate the information by adding detail to the analysis at the subcategory level. This was considered for categories 5105 and 5106, which have much higher values than the others for the maximum stack height by excess, 9.81m and 10.56m, respectively.

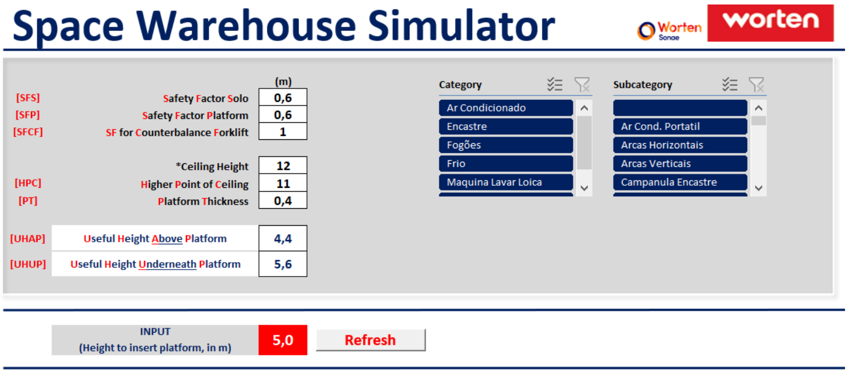
5.3.2 Analysis II

This second analysis began with the construction of an *Excel* database, which would be the source of information for the desired simulator, in which it would be possible to visualize which products could be stored under and above the platform, taking into account several variants that will be explained, and being able to insert various inputs to simulate diverse scenarios. An overall overview of the simulator can be seen in appendix C, figure C.5.

Simulator Fixed Values

Now all the base values that are parameterized in the simulator will be addressed and explained, to always keep up with the reality of the operation and its needs. The explanation will try to always follow the order of ideas in which each variable was thought of.

Figure 5.2, shows the initial variables that had to be defined and taken into account when starting all calculations. This figure also shows the initial frame of the simulator.



Space Warehouse Simulator

		(m)
[SFS]	Safety Factor Solo	0,6
[SFP]	Safety Factor Platform	0,6
[SFCF]	SF for Counterbalance Forklift	1
	*Ceiling Height	12
[HPC]	Higher Point of Ceiling	11
[PT]	Platform Thickness	0,4
[UHAP]	Useful Height Above Platform	4,4
[UHUP]	Useful Height Underneath Platform	5,6

INPUT
(Height to insert platform, in m) 5,0

Figure 5.2: Simulator Starting Variables

- The first factor to take into account is the maximum storage possibility in height, based on the ceiling height and all the piping in the warehouse. The higher point of the ceiling is equal to 11m. As mentioned in section 5.1, the ceiling height is 12m, in theory, it is possible to take advantage of 91.67% of the warehouse height. This is a fixed value and it is represented in figure 5.2 by Higher Point of Ceiling (HPC).

Afterwards, the factors related with safety are considered.

- One of the factors that need to be taken into account is the safety factor underneath the platform. This factor has to ensure that the equipment when handling the products can do so without any damage. When the counterbalance forklift with clamps lifts a stack of products, it must have a height to lift the product from the stack, plus consideration of the height of the clamps themselves and the height of the product being lifted. This factor was operationally tested, considering the worst-case scenario in terms of handling which is to lift only one product from the top of a stack at its maximum. This value is 0.6m, which comprises 0.2m for the product to be lifted plus 0.4m of clearance for clamp considerations and the height of the products. These last two variables need to be taken into account, as the product to be lifted, may be higher or lower than the clamps of the equipment handling it. If more than one stack of products is lifted, this factor loses relevance, because the equipment clamps will always hold the middle of the stack of products to be lifted. This factor is called Safety Factor Solo (SFS).
- The same reasoning has been done for the upper part of the platform, now relative to the warehouse ceiling. This factor is called the Safety Factor Platform (SFP).
- Finally, in terms of safety, the height of the largest equipment to be used under and above the platform also had to be taken into account. This equipment is a counterbalance forklift with clamps, shown in figure 5.3. There are two models of this equipment inside the warehouse, with different heights, and for both top and bottom only the one with the lower height, 2.30m, will be used. The 2.30m value was rounded up to 2.50m. A safety factor of 1m was then considered, to be added to the minimum 2.30m for the useful height of the platform. This value is represented with the acronym SFCF.
- The next value to enter into the calculations is the, Platform Thickness (PT). A base value of 0.4m has been given by the supplier for this parameter. Taking into account that this value will already have some slack, always ensuring the stability, strength, and robustness of the structure of the platform, for the type of support loads for which it is intended.

The next two values are no longer directly fixed, but calculated from the factors explained above.

- The first value calculated is the Useful Hight Above Platform (UHAP), this value in meters, gives what the useful height above the platform is, after considering all the variables explained so far. So

Figure 5.3: Higher Equipment: Counterbalance Forklift with Clamps

the formula to calculate this height is, equation 5.12:

$$UHAP = HPC - UHUP - PT - SFP \tag{5.12}$$

- The second variable is the Useful Hight Underneath Platform (UHUP), also in meters, gives the same that the previous one, but for underneath the platform. The formula that the simulator uses to calculate this value is, equation 5.13:

$$UHUP = INPUT + SFS \tag{5.13}$$

- The last parameter to explain is INPUT, this value is the number entered into the simulator by the user, in meters, concerning the platform height before inserting the operational safety factors.

It is also important to note that the height required underneath and above the platform for the equipment to pass is taken into account as follows. When the user enters an INPUT value that does not leave the safety margin explained previously for this factor, a warning message appears, saying that the value entered has to be higher or lower to be able to do the handling in the area under study. These two possible errors can be observed in figure 5.4.

The two *slicers*, an *Excel* functionality, that can be seen on the right side of figures 5.2 and 5.4, allow the user to filter what they want to observe in terms of future calculations. The user can select none of the categories and subcategories, so the simulator considers all of them, or can choose which category and subcategory you want to observe in particular detail.

Data Base Simulator

The construction of the simulator database was the most complex and time-consuming part, 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* has about 61 columns and 286 203 rows. Therefore, only the defined formulas of the relevant columns to the problem's outputs will be explained, other columns are

(m)
[SFS] Safety Factor Solo 0,6
[SFP] Safety Factor Platform 0,6
[SFCF] SF for Counterbalance Forklift 1
*Ceiling Height 12
[HPC] Higher Point of Ceiling 11
[PT] Platform Thickness 0,4
[UHAP] Useful Height Above Platform 0,4 Atention! Counterbalance Forklift Does Not Fit Above, please insert a lower INPUT value
[UHUP] Useful Height Underneath Platform 9,6
INPUT (Height to insert platform, in m) 9,0

(m)
[SFS] Safety Factor Solo 0,6
[SFP] Safety Factor Platform 0,6
[SFCF] SF for Counterbalance Forklift 1
*Ceiling Height 12
[HPC] Higher Point of Ceiling 11
[PT] Platform Thickness 0,4
[UHAP] Useful Height Above Platform 8,4
[UHUP] Useful Height Underneath Platform 1,6 Atention! Counterbalance Forklift Does Not Fit Underneath, please insert a higher INPUT value
INPUT (Height to insert platform, in m) 1,0

Figure 5.4: Warning Messages Regarding the Equipment Safety Factor, SFCF

auxiliary calculations.

The first fifteen columns are relative to the *Excel* extracted from the 2021 solo stock already mentioned above. These columns incorporate the following information[2]: SKU number; location code where each SKU was stored on that day when the script was read; Category; Category Name; Subcategory; Subcategory Name; Picking Zone for that location, which gives information on the type of location, whether it is large or small; SKU Description; Date the data was read; Stacking Height for each SKU; SKU Quantity; SKU Height; SKU Lenght; SKU Width; Location Space, m^2. These columns have no embedded calculation, they are just information from the WMS system.

In one of the initial versions of the simulator, not all this information was incorporated. For example, at the beginning it was not considered the square meters occupied by each location, so the only variable to be considered for the platform height was the height of each stack of products, with the stacking factor given by the supplier. What happened at the end of this version of the simulator was that the product units only moved up the platform when either the stacking factor or the platform height did not allow for more stacking. In terms of space, there was no limit, and it was possible to store infinitely. It was necessary to make a new version of the simulator that could contemplate the square meters of the available locations, and at this point, the simulator started contemplating two variables, both the heights of the products (as before), but now with the space occupied by each stack.

One of the first columns in terms of calculations in the latest version of the simulator is the *Base Area*

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[2] As evidenced at the beginning of this chapter, all information was taken from the Wortens´ internal system with the use of programming queries, using the *software* SQL.

of each product that was stored in the solo in the year 2021. This calculation was performed as follows, equation 5.14:

$$BaseArea = Lenght \times Width \times 10^{-4} \tag{5.14}$$

The multiplication by 10^{-4}, is due to the need convert cm^2 to m^2. Usually, all variables within the information system are cm.

The next need was to figure out how many theoretical stacks could be made of a given SKU stored in a location according to its dimensions. For this estimation, it resorted to an *Excel* function called, *ROUNDUP*. So, a column was created called, *Number of Theoretical Stacks*, which follows the following reasoning, equation 5.15:

$$TheoreticalStacks = \frac{LocationArea}{BaseArea} \tag{5.15}$$

Both Location Area and Base Area have the unit m^2. This Location Area is the area of the total corresponding location.

The next variable is the Theoretical Area for that SKU, that is, considering the number of theoretical stacks and the area of its base, how much space, in m^2, does it occupy. See, equation 5.16:

$$TheoreticalArea = TheoreticalStacks \times BaseArea \tag{5.16}$$

The next account, allows you to see what the theoretical quantity of that SKU is, at that location. Considering the theoretical number of stacks by the stacking factor coming from the factory supplier, you can understand in theory how many units you could put in that location, of that particular product, equation 5.17:

$$TheoreticalQTY = TheoreticalStacks \times StakingFactor \tag{5.17}$$

In the next columns, it starts to take into account the stock values stored in 2021. Thus, a balance column was made between the theoretical quantity that would be possible to store of that SKU, in that particular location, minus the quantity that was stored in 2021, for each reading made. One is then left to figure out how much slack there was in what the location offered, and what was used in space terms, equation 5.18:

$$QTYBalance = TheoreticalQTY - QTY2021 \tag{5.18}$$

The next column allows to understand how many stacks of that SKU were made in 2021, according to the amount of products that were in that location, by the stacking factor also coming from the factory. For this column, *Excel* function *ROUNDUP* was used, equation 5.19:

$$2021Stacks = \frac{QTY2021}{StakingFactor} \tag{5.19}$$

Then the same reasoning was done as before (regarding the Balance QTY, in equation 6.18), comparing the theoretical number of piles that could be made for that SKU, at that location, with the number of piles that were made in 2021, equation 5.20:

$$StacksBalance = TheoreticalStacks - 2021Stacks \tag{5.20}$$

Now, with the columns for the number of piles made, and the quantity stored, in 2021, it is then possible what the area of the location used was, using the following formula, equation 5.21:

$$2021Area = 2021Stacks \times QTY2021 \tag{5.21}$$

Therefore, now it can also be calculated what the occupancy rate of the location is, considering the area that has been used, with the area available for use, equation 5.22:

$$AreaUsedRate = \frac{2021Area}{TheoreticalArea} \tag{5.22}$$

The Pile Height is the maximum stack height of a given SKU. In other words, it is the relation between the height of the product considered and its stacking factor. The multiplication by 10^{-2}, is done to convert the height in cm to m, equation 5.23:

$$PileHeight = Height \times 10^{-2} \times StackingFactor \tag{5.23}$$

Using an *Excel*, *IF* function, the following condition was performed, which is intended to be a validator as to whether or not it is possible to store the entire maximum stack of products under the platform, equation 5.24, returning one if true and zero if false. The same thought was made for storing above the platform, see equation 5.25:

$$PossibilityStoringUnderneath = IF(PileHeight > UHUP; 1; 0) \tag{5.24}$$

$$PossibilityStoringAbove = IF(PileHeight > UHAP; 1; 0) \tag{5.25}$$

New SH has the objective that, if the value of the height of a maximum stack cannot be stored under the platform, due to the height of the platform, then the simulator will decrease its stacking factor coming from the supplier until it gets a stack height that fits under the structure, equation 5.26. This decreased stacking factor is the (SH-1) written in the examples below, the next part of the equation will be (SH-2), then (SH-3), and so on. The same reasoning is done for above the platform, equation 5.27. However, instead of using the variable UHUP, you use UHAP:

$$NewSH(Under) = IF(PileHeight > UHUP; IF(Height \times (SH-1) \times 10^{-2} > UHUP; ...) \tag{5.26}$$

$$NewSH(Above) = IF(PileHeight > UHAP; IF(Height \times (SH-1) \times 10^{-2} > UHAP; ...) \tag{5.27}$$

The next equation allows obtaining what is the theoretical number of piles with the new stacking factor in use. This new stacking factor comes from equations 5.26 and 5.27 (under and above, respectively), so when simulating a platform height, *Excel* reason and realize: that the maximum number is SH, but how many units can be stacked in height? SH-1? SH-2? SH-3? Then the rest will have to be stored on top of the platform. The Theoretical QTY (Under) will only be explained later. For these equations, the *ROUNDUP* function was also used. This reasoning will be the same for both floors of the platform, solo, equation 5.28, and above, equation 5.29:

$$TheoreticalStacks(NewSH)Under = \frac{TheoreticalQTY(Under)}{NewSH(Under)} \tag{5.28}$$

$$TheoreticalStacks(NewSH)Above = \frac{TheoreticalQTY(Above)}{NewSH(Above)} \tag{5.29}$$

Equations 5.30 and 5.31 continue to follow the same logic as before, which is the recalculation of the parameters with the new stacking factors as a function of the inserted platform height and its safety factors. Equation 5.30, provides the new number of stacks made with the quantities of products stored of that SKU, in that location, with the new stacking factor, for under platform. Equation 5.31 gives the same result but for the above platform. Again, the *Excel ROUNDUP* function was used.

$$2021Stacks(NewSH)Under = \frac{2021QTY(Under)}{NewSH(Under)} \tag{5.30}$$

$$2021Stacks(NewSH)Above = \frac{2021QTY(Above)}{NewSH(Above)} \tag{5.31}$$

Regarding the areas, the two following calculations (5.32 and 5.33) allow the simulator to obtain what the theoretical area will be, already incorporating the new stacking factors previously obtained, as well as the theoretical number of piles already recalculated also based on the previous value. The base area is the area of the product base, as previously explained (see equation 5.14).

$$TheoreticalArea(NewSH)Under = TheoreticalStacks(NewSH)Under \times BaseArea \tag{5.32}$$

$$TheoreticalArea(NewSH)Above = TheoreticalStacks(NewSH)Above \times BaseArea \tag{5.33}$$

Now it was necessary to calculate the new footprint in 2021 as well, if the platform existed, i.e. with the new stacking factors as well. This area is calculated from the value obtained from new stacks (also with the new stacking factor), multiplying by the area of the product base. This formula is necessary because often the maximum capacity has not been reached in terms of square meters of the warehouse floor. This calculated area is the area that was in a past scenario occupied if the platform was already in place. See equations 5.34 and 5.35.

$$2021Area(NewSH)UnderOccupied = 2021Stacks(NewSH)Under \times BaseArea \tag{5.34}$$

$$2021Area(NewSH)AboveOccupied = 2021Stacks(NewSH)Above \times BaseArea \tag{5.35}$$

Then, after all these calculations, a balance was made, for the new simulator parameters, incorporating the platform, of what the free space in square meters would be in 2021. This difference is made based on the theoretical area (with the new stacking factor) by subtracting the area that was effectively occupied in 2021 (also with the new stacking factor), both for under and above the platform, observe equations 5.36 and 5.37.

$$2021Area(NewSH)UnderFree = TheoreticalArea(NewSH)Under - 2021Area(NewSH)UnderOccupied \tag{5.36}$$

$$2021Area(NewSH)AboveFree = TheoreticalArea(NewSH)Above - 2021Area(NewSH)AboveOccupied \tag{5.37}$$

Coming to the end of the explanation of the simulator database, it is still important to incorporate the calculation of quantities. The next four formulas show the actual quantities effectively stored in 2021, but with the division of the scenario of the existence of the platform, under and above (equations 5.38 and 5.39). For the first two equations present below, it resorted to the use of the *Excel* function, *IF*. As well as, the theoretical quantities that would be stored as the same logic of previous ideas (equations 5.40 and 5.41).

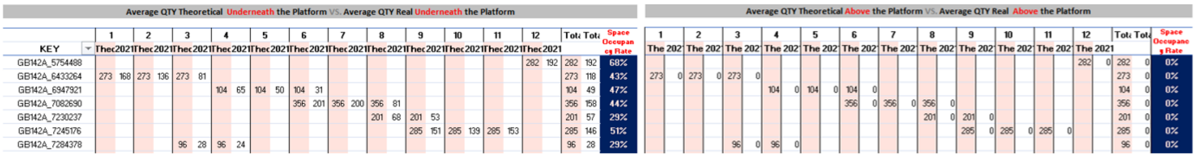
$$QTYStoredUnderReal = IF(QTY2021 >= TheoreticalQTYUnder; TheoreticalQTYUnder; QTY2021) \tag{5.38}$$

$$QTYStoredAboveReal = IF(QTY2021 >= TheoreticalQTYAbove; TheoreticalQTYAbove; QTY2021) \tag{5.39}$$

$$QTYTheoreticalUnderPlatform = TheoreticalStacks \times NewSH(Under) \tag{5.40}$$

$$QTYTheoreticalAbovePlatform = TheoreticalStacks \times NewSH(Above) \tag{5.41}$$

Concluding the explanation of the columns of the database created for the simulator, a last one was added, in which it was possible to identify what type of location and product was being referred to. Thus, the key of the simulator is the column that allows the identification, with the help of the *Excel* function, *Concatenate*, *Location_Item*, see figure 5.5.



Average QTY Theoretical Underneath the Platform VS. Average QTY Real Underneath the Platform

	1		2		3		4		5		6		7		8		9		10		11		12		Tot	Tot	Space Occupancy Rate
KEY	Thec	2021	Thec	2021	Thec	2021	Thec	2021	Thec	2021	Thec	2021	Thec	2021	Thec	2021	Thec	2021	Thec	2021	Thec	2021	Thec	2021			
GB142A_5754488																							282	192	282	192	68%
GB142A_6433264	273	168	273	136	273	81																			273	118	43%
GB142A_6947921							104	65	104	50	104	31													104	49	47%
GB142A_7082690											356	201	356	200	356	81									356	158	44%
GB142A_7230237															201	68	201	53							201	57	29%
GB142A_7245176																	285	151	285	139	285	153			285	146	51%
GB142A_7284378					96	28	96	24																	96	28	29%

Average QTY Theoretical Above the Platform VS. Average QTY Real Above the Platform

1		2		3		4		5		6		7		8		9		10		11		12		Tot	Tot	Space Occupancy Rate
The	202	The	202	The	202	The	202	The	202	The	202	The	202	The	202	The	202	The	202	The	202	The	2021			
																						282	0	282	0	0%
273	0	273	0	273	0																			273	0	0%
						104	0	104	0	104	0													104	0	0%
										356	0	356	0	356	0									356	0	0%
														201	0	201	0							201	0	0%
																285	0	285	0	285	0			285	0	0%
				96	0	96	0																	96	0	0%

Figure 5.5: Simulator Pivot Tables using the Key: *Location_Item*

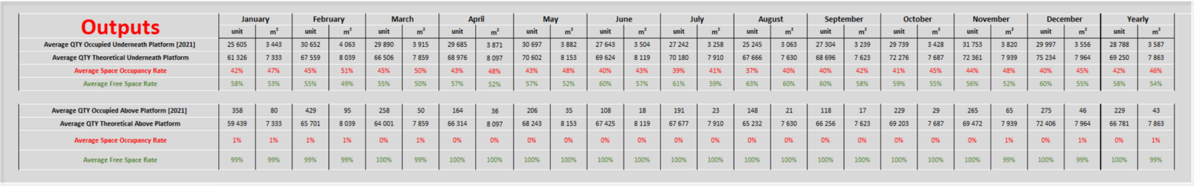
Simulator Outputs

After following the logic of ideas, starting with an explanation of the simulator's fixed values and safety factors, moving on to a detailed explanation of the most important columns in the database, it is then necessary to look at the visualizations in terms of output.

What initiates the entire generation of simulator outputs is the refresh button, see figure 5.6. Here, as explained above, the user enters the height at which they want to simulate the action of the platform, and all calculations of safety factors and the entire database are performed (including the update of the pivot tables, figure 5.5), automatically providing the outputs that are presented in the table shown in figure 5.7, as well as all the graphs are shown in figure 5.8[3]. The refresh button is the start of the entire simulation, allowing all values to be generated and calculated by the simulator. This refresh button is executed in *Excel*, with the help of macro functionalities.


INPUT
(Height to insert platform, in m)
5,0

Figure 5.6: Simulator Refresh Button



Outputs	January		February		March		April		May		June		July		August		September		October		November		December		Yearly	
	unit	m^2	unit	m^2	unit	m^2	unit	m^2	unit	m^2	unit	m^2	unit	m^2	unit	m^2	unit	m^2	unit	m^2	unit	m^2	unit	m^2	unit	m^2
Average QTY Occupied Underneath Platform [2021]	25 605	3 443	30 652	4 063	29 890	3 915	29 685	3 871	30 697	3 882	27 643	3 504	27 242	3 258	25 245	3 063	27 304	3 239	29 739	3 428	31 753	3 820	29 997	3 556	28 788	3 587
Average QTY Theoretical Underneath Platform	61 326	7 333	67 559	8 039	66 506	7 859	68 976	8 097	70 602	8 153	69 624	8 119	70 180	7 910	67 666	7 630	68 696	7 623	72 276	7 687	72 361	7 939	75 234	7 964	69 250	7 863
Average Space Occupancy Rate	42%	47%	45%	51%	45%	50%	43%	48%	43%	48%	40%	43%	39%	41%	37%	40%	40%	42%	41%	45%	44%	48%	40%	45%	42%	46%
Average Free Space Rate	58%	53%	55%	49%	55%	50%	57%	52%	57%	52%	60%	57%	61%	59%	63%	60%	60%	58%	59%	55%	56%	52%	60%	55%	58%	54%
Average QTY Occupied Above Platform [2021]	358	80	429	95	258	50	164	36	206	35	108	18	191	23	148	21	118	17	229	29	265	65	275	46	229	43
Average QTY Theoretical Above Platform	59 439	7 333	65 701	8 039	64 001	7 859	66 314	8 097	68 243	8 153	67 425	8 119	67 677	7 910	65 232	7 630	66 256	7 623	69 203	7 687	69 472	7 939	72 406	7 964	66 781	7 863
Average Space Occupancy Rate	1%	1%	1%	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	1%	0%	1%
Average Free Space Rate	99%	99%	99%	99%	100%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	99%	100%	99%	100%	99%

Figure 5.7: Simulator Outputs Board Presentation

Looking at the four graphs in figure 5.8, the first two on the left-hand side is for results in terms of units, and the two on the right-hand side are in square meters. This distinction of outputs is important because evaluating space in terms of units can sometimes be unreliable because it depends a lot on the type of equipment aimed to store at 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. Thus, presenting these two variables, units, and square meters, allows for a more detailed analysis of the results obtained.

In the graphs presented (figure 5.8), it is possible to observe green bars and red bars[4]. The green bars show the average percentages of free space, for each month. The red bars are exactly the opposite, average percentages of space occupied, for each month as well. Both variables evaluate relative to the stock that was stored throughout the year 2021, with the variant of the desired structure insertion, the

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[3] On the simulator the graphs are shown one above the other, but to fit in the thesis document it was presented two side by side.

[4] The values that are in the red bars and that are presented in negative are nonnegative values, they are normal absolute values equal to those presented in the green bars, however, to have this visualization of bars for both sides of the axis, it was necessary to put one of the range of values to negative.

Figure 5.8: Simulator Outputs Graphs: Average Space Rate %, in Units (on the left) and in m^2 (on the right)

platform. Thus, 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. Also, for each variable output, there is a graph underneath and another above the platform. In figure 5.8, the first two graphs are regarding the solo part of the platform (underneath), and the other two below are concerning the space above the structure.

Scenarios Simulation

To finalize the section 5.3, related to spatial analysis, and complete the second section 5.3.2 analysis, based on the designed simulator, ten simulations were run to achieve an optimal result 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. All this reasoning will be explained through the text, and in more detail in chapter 6.

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 problem under study. All simulations were run 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. Thus, as this database of the stored stock, was all that was actually in the area under study, only some categories or subcategories should be filtered out if you feel the need to exclude some typology of products.

Therefore, 10 simulations of INPUT values for the platform height were run in the designed simulator. It was started by entering an INPUT value of 3.5m, which is the minimum value for the height, considering the necessities for the type of equipment models that need to circulate under the platform and perform the handling of the respective products. This first simulation value also allows us to understand how product storage can be optimized under the platform, due to the stacking height factor. The reasoning lies on: if the space can be optimized under the platform, and also allows the stock of products to satisfy one day of operations, then the space above can be a complement of the storage necessities.

For the value of 3.5m, useful heights down and up the platform were obtained, 4.1m and 5.9m, respectively. These heights result in an occupancy percentage in terms of area, square meters to the ground, of 51% below the platform, and 2% above the platform, considering the stock stored in 2021.

More simulations needed to be performed to be able to compare the outputs for different heights of the structure. All simulation results are consolidated in graph 5.9.

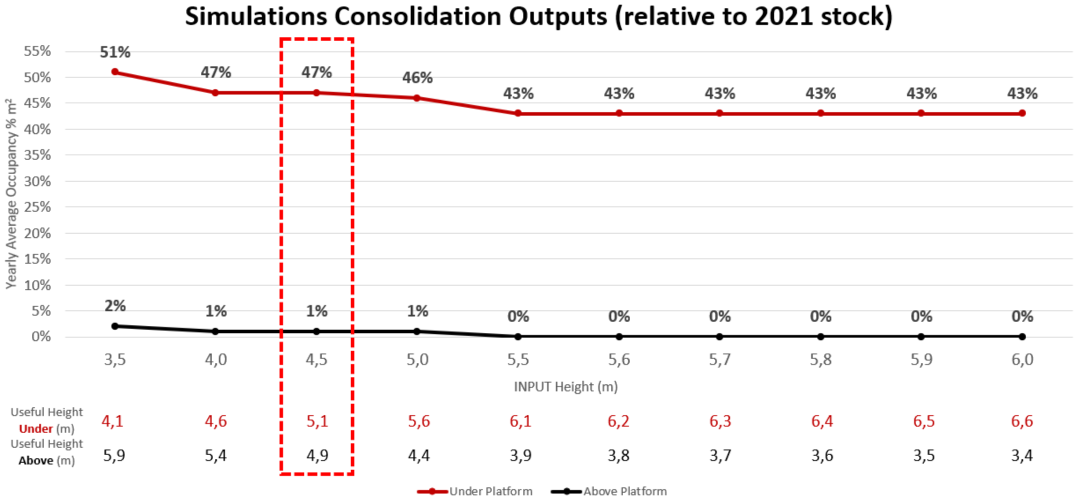


Figure 5.9: All Executed Simulation Values from Space Warehouse Simulator

In the second simulation an increment of 0.5m was made to the INPUT value, inserting the value 4.0m. It was then verified that for usable heights below 4.6m and above the platform of 5.4m, the average under-platform occupancy percentages experienced during the year 2021 decreased from 51% to 47% (a decrease of 4 percentage points). At the top of the platform, the percentage also dropped by one percentage point, now showing a value of 1

However, in the third and following simulation, the same 0.5m increase in INPUT was given, providing usable heights of 5.1m and 4.9m, with the same occupancy percentages determined in the second simulation. In this third run of the simulator, it is possible to highlight a factor that may be important in the selection of the optimal height, which lies in having, practically, the same value for the variables of heights both for the bottom and the top of the structure, this may bring numerous advantages for the storage of products.

The fourth simulation was run, with the same 0.5m increment, to understand how the simulator behaved and returned very different outputs from the previous ones. There was a decrease of one percentage point for the average occupancy percentage under the platform, now around 46%. At the top, the percentages remained the same, 1%.

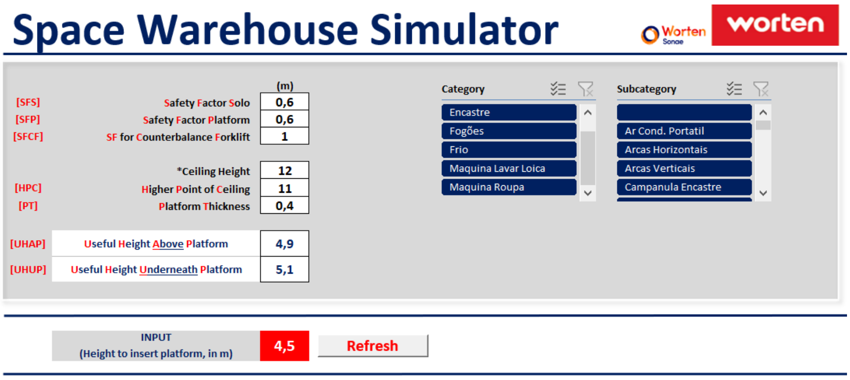
The same reasoning was performed for another simulation, again increasing the INPUT value by 0.5m. The results obtained now are the largest turning point felt to date. For an INPUT height of 5.5m, there is a useful availability of 6.1m below the structure and 3.9m above. The average annual occupancy percentages, are now 43% above the platform and 0% below. Here there has been a drop of three percentage points at the bottom, with almost zero occupancies at the top of the platform.

At 3.9m, the minimum height that must exist both below and above the platform is approaching, due to the operation of the equipment as already explained. Thus, in the next simulations, the increment given to the INPUT value will no longer be 0.5m, but 0.1m. It was verified that for the INPUT values of 5.6m, 5.7m, 5.8m, 5.9m, and 6.0m, the variables relating to the average percentage of occupancy both below and above the platform remained constant, at 43% and 0%, respectively. The only fluctuations were in the values of useful heights for both floors of the platform (floor 0 and floor 1), see graph 5.9, to observe all simulation results.

It was then determined, looking at all ten simulations performed, graph 5.9, that the optimum height in terms of storage considering all products characteristics would be with an INPUT value at 4.5m, resulting in a useful height below the platform of 5.1m and below of 4.9m, 5.10. Observing the result of all simulations, this INPUT value of 4.5m was decided as optimal, because for the operation's functioning 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 it 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 inserts further advantages, such as oversizing given storing the tallest product ever stored, which is an American Refrigerator with a height of 2.5m and its 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 5m. A height of 5.1m is available at the bottom and 4.9m at the top, even though the latter is less than 5m, 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 0.1m required. Simulations stopped at an INPUT height of 6.0m because the useful height above the platform is no longer able to contemplate all safety factors, namely the one that considers the height of the counterbalance forklift with clamps. Thus, after obtaining this result, the simulations were interrupted, because all following ones could no longer fit the required operational safety.

This is the time that provides less compromise and possible exclusions of product typologies for storage, allowing variations in the product ranges purchased by the company for later sale to the customer.

Looking at the output table and graphs, 5.11 and 5.12, respectively, it can be seen that over the year, the average percentage of space in terms of square meters occupied under the platform by the products



Space Warehouse Simulator

		(m)
[SFS]	Safety Factor Solo	0,6
[SFP]	Safety Factor Platform	0,6
[SFCF]	SF for Counterbalance Forklift	1
	*Ceiling Height	12
[HPC]	Higher Point of Ceiling	11
[PT]	Platform Thickness	0,4
[UHAP]	Useful Height Above Platform	4,9
[UHUP]	Useful Height Underneath Platform	5,1

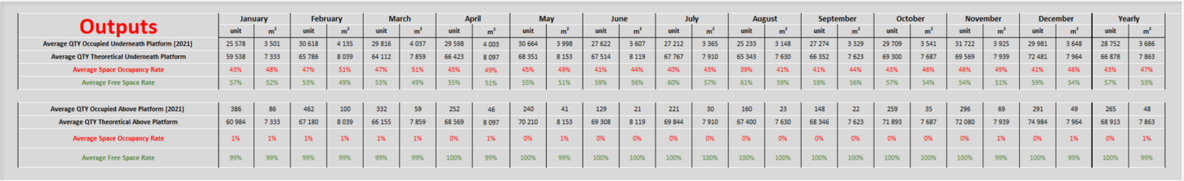
Category: Encastre, Fogões, Frio, Maquina Lavar Loica, Maquina Roupa

Subcategory: Ar Cond. Portatil, Arcas Horizontais, Arcas Verticais, Campanula Encastre

INPUT (Height to insert platform, in m): 4,5

Figure 5.10: Executed Simulation for Optimal INPUT height of 4.5m

stored in 2021 varies between 41% and 51%. By averaging these occupancy's, it was obtained the value of 47% down and 1% up. This very low percentage of products stored on top of the platform indicates that even in terms of consolidations between heights and stacking factors, for few products the requirements for maximum stack values are met. Therefore, for an even more detailed analysis, each product category was selected to understand in a more isolated way, how the simulator behaves and what values it returns.



Outputs	January		February		March		April		May		June		July		August		September		October		November		December		Yearly	
	unit	m²	unit	m²	unit	m²	unit	m²	unit	m²	unit	m²	unit	m²	unit	m²	unit	m²	unit	m²	unit	m²	unit	m²	unit	m²
Average QTY Occupied Underneath Platform [2021]	25 578	3 501	30 618	4 135	29 816	4 037	29 598	4 003	30 664	3 998	27 622	3 607	27 212	3 365	25 233	3 148	27 274	3 329	29 709	3 541	31 722	3 925	29 981	3 648	28 752	3 686
Average QTY Theoretical Underneath Platform	59 538	7 333	65 786	8 039	64 112	7 859	66 423	8 097	68 351	8 153	67 514	8 119	67 767	7 910	65 343	7 630	66 352	7 623	69 300	7 687	69 569	7 939	72 481	7 964	66 878	7 863
Average Space Occupancy Rate	43%	48%	47%	51%	47%	51%	45%	49%	45%	49%	41%	44%	40%	43%	39%	41%	41%	44%	43%	46%	46%	49%	41%	46%	43%	47%
Average Free Space Rate	57%	52%	53%	49%	53%	49%	55%	51%	55%	51%	59%	56%	60%	57%	61%	59%	59%	56%	57%	54%	54%	51%	59%	54%	57%	53%
Average QTY Occupied Above Platform [2021]	386	86	462	100	332	59	252	46	240	41	129	21	221	30	160	23	148	22	259	35	296	69	291	49	265	48
Average QTY Theoretical Above Platform	60 984	7 333	67 180	8 039	66 155	7 859	68 569	8 097	70 210	8 153	69 308	8 119	69 844	7 910	67 400	7 630	68 346	7 623	71 893	7 687	72 080	7 939	74 984	7 964	68 913	7 863
Average Space Occupancy Rate	1%	1%	1%	1%	1%	1%	0%	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	1%	0%	1%
Average Free Space Rate	99%	99%	99%	99%	99%	99%	100%	99%	100%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	99%	100%	99%	100%	99%

Figure 5.11: Simulator Outputs Board of Optimal Simulation, for INPUT height of 4.5m

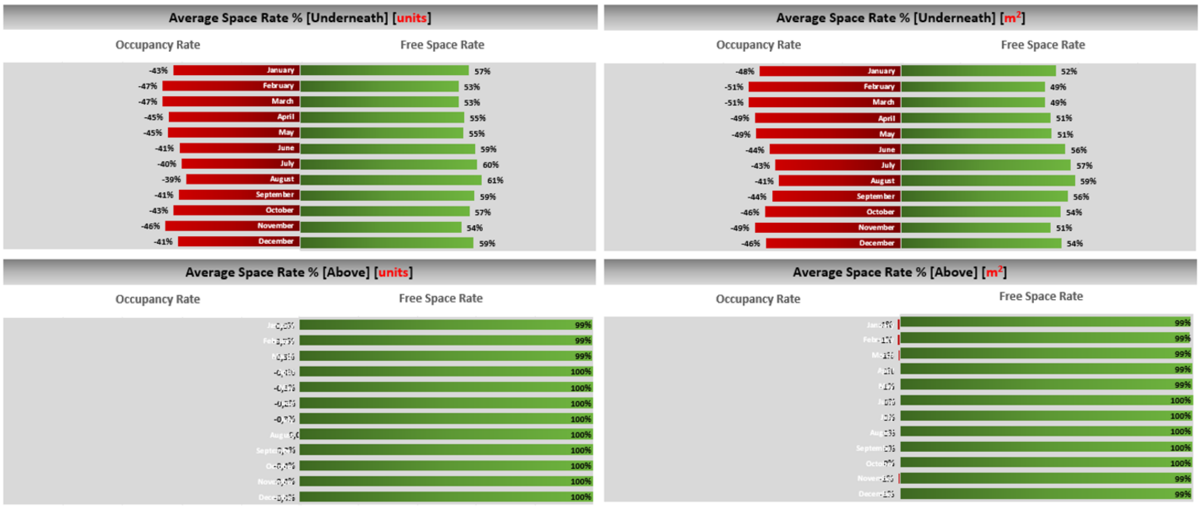


Figure 5.12: Simulator Outputs Graphs of Optimal Simulation, for INPUT height of 4.5m

The two graphs in the first column of figure 5.13, highlight the outputs for the Ar Condicionado category. Next to it is the Encastre category. The simulator also allows the selection of products down to their subcategory, however, this degree of detail will not be used in this master's thesis. The graphics presented, only have the visualization related to square meters because the two variables considered for evaluation focus on heights and areas. Performing now an analysis of the output values, it can be seen that for the air conditioning category, the average occupancy percentages during the year 2021, for the platform scenario, have values between 68% (June) and 92% (March), below the platform. Above the platform there is still some percentage of occupancy in the first three months of the year, ranging between 18% (January) and 22% (February) of average space occupancy, however, these values reduce dramatically in the remaining annual period. The Encastre category, graph 5.13, on the right side, shows the results for the platform height considered. It can be seen that the average percentage of occupancy under the platform fluctuates between 33% and 40%. Above the structure, on the other hand, the platform is not used, and 100% of the locations are free all year round.

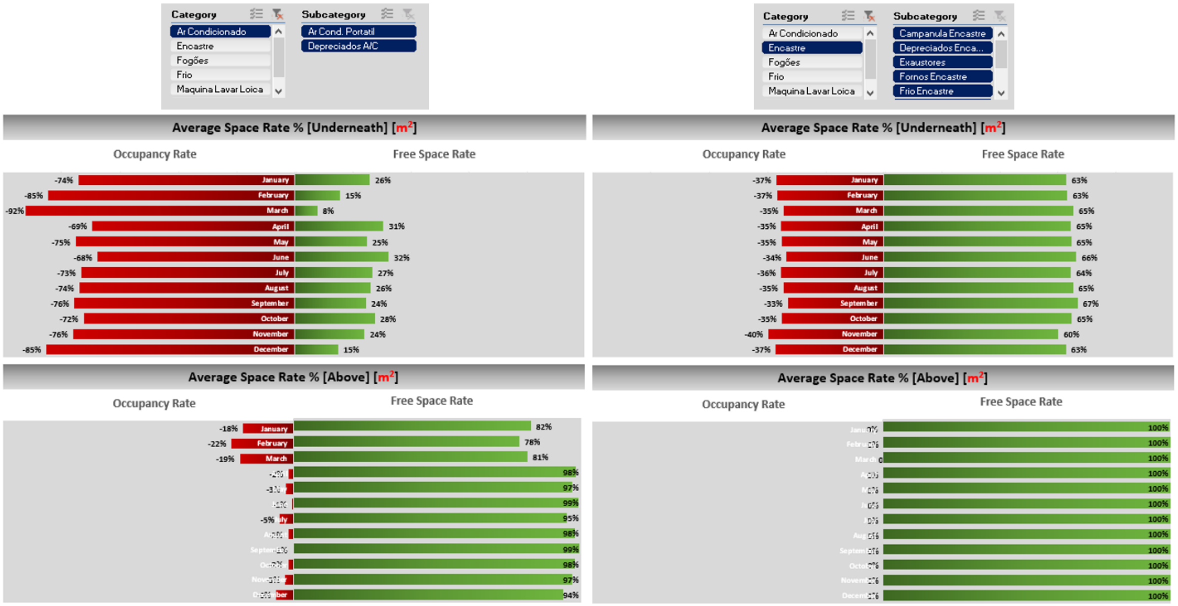


Figure 5.13: Simulator Outputs Graphs of Optimal Simulation, for INPUT height of 4.5m, considering Ar Condicionado and Encastre Categories

The graph 5.14 shows the results for Fogões (left side) and Frio (right side) categories. In Fogões it is possible to see that on average, the locations are occupied below the platform, between 33% and 44%. While on top, only in September an average occupancy of 1% was obtained, for the rest of the year, the top of the platform would be empty and available to receive stock, considering this scenario. In the Frio, a higher percentage of average occupancy is observed, between 44% and 60% in the lower part of the structure. On the first floor of the platform, an occupancy of 2% is obtained in February, 1% in all the remaining months except for June and August when the platform has 0% occupancy, in other words, it is practically free.

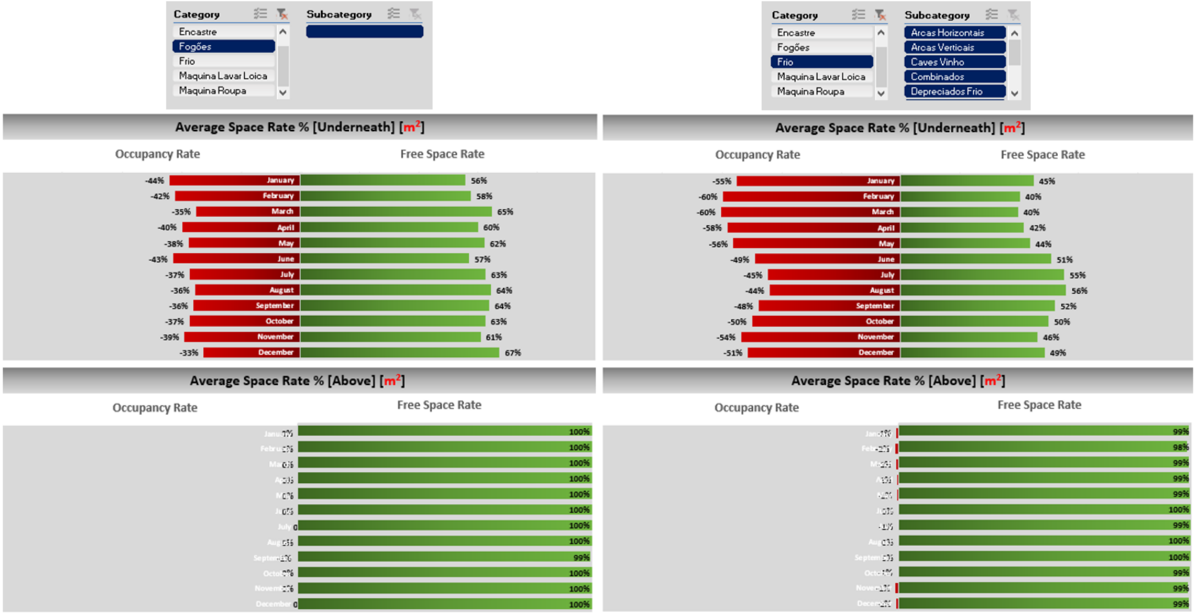


Figure 5.14: Simulator Outputs Graphs of Optimal Simulation, for INPUT height of 4.5m, considering Fogões and Frio Categories

Finally, it remains to make considerations about the Maquina Lavar Loiça and Maquina Roupa categories, graphs on the left and right, respectively, of figure 5.15. In both categories, the average monthly occupancy percentages are similar for the bottom of the platform, with Maquina Lavar Loiça ranging between 37% and 49%, and for Maquina Roupa from 38% to 48%. However, above the platform, in the first case of the Maquina Lavar Loiça, this space is practically empty, with an average occupancy throughout the year of 0%. In the case of the Maquina Roupa, the bars vary between 0% for April, May, June, July, August, September, October, and December; 1% for February, March, and November, and a propensity of 2% only for January.

In conclusion of the values obtained in the previous graphs, it is possible to see that in all cases except for the air conditioning category, the upper part of the platform remains mostly free and unoccupied. However, these products are not a concern, because they are very seasonal products that need coverage only during some months of the year, with the arrival of heat. This fact allows us to realize that by building this structure the available space would double in most months of the year, analyzing the same range of products. Most of the products that will be placed above the platform in all the simulated scenarios are due to the reason that the maximum stacking factor is not allowed to happen because of the platform itself. Underneath the structure, all categories, except for Ar Condicionado and Frio always have an average occupation of space in terms of square meters around 40% and 50%. This low percentage is justified by the low efficiency of this type of system in lock stacking, taking into account

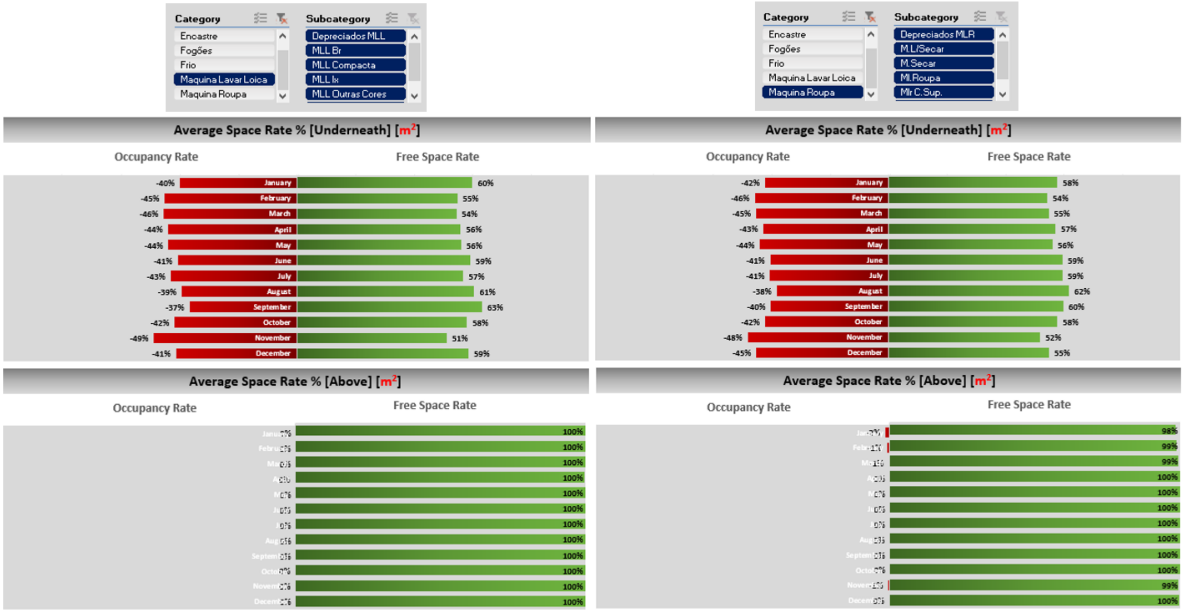


Figure 5.15: Simulator Outputs Graphs of Optimal Simulation, for INPUT height of 4.5m, considering Maquina Lavar Loiça and Maquina Roupa Categories

the needs of aisles and spacing for the handling of products, and also not forgetting the fluctuations of SKUs entering the warehouse. This always maintains a dedicated storage policy, placing only one SKU in each location. Future and conclusions will be made in the next chapters, chapter 6 and chapter 7.

5.4 Operational and Investment Costs

This section will address the costs[5] involved in both the as-is and-to-be system with the implementation of a platform/mezzanine in the study area. This presentation will be accompanied by evolutionary graphs of the growing needs, as well as the analysis of the return on investment and the payback period. By measuring both of these two indicators, it would be possible to assess the investment profitability and to compare it with other investments. This is a direct measurement of the profit made in response to the given metric, always related to the cost. Calculating the payback period also allows estimating the length interval in time to repay a particular investment cost.

5.4.1 System As Is

For cost analysis, we will only consider the cost entries that will represent a variation between the as-is situation and the to-be situation. This means that costs such as renting the space in the central operations warehouse (Plaza II), or the direct cost of the number of workers that intervene directly in the

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[5] All values shown in euros for the as-is system are proportionally adulterated to protect the interests and confidentiality of the company.

project area will not be considered, only the changes to these values.

Thus, according to the logic of ideas presented, 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 services, to meet the space needs of the products that need to be stored and stocked, to fulfill and feed Worten daily operations.

Graph 5.16, shows, for the years 2020[6], 2021 and also for the already available months of 2022, the number of square meters rented to a third party company. Analyzing this graph in detail, it can be seen that in the year 2020 the trend was always increasing, except for the last two months of the year when the need for rented space outside decreased. In the year 2021, the values of the end of the previous year were maintained until April when there was again a regression in the need for outsourcing, however, this value rose again in the following months, reaching a constant value of 7 000 m^2 in the second half of the year. Making a direct comparison between 2021 and 2020, it is possible to see an increase of 11% (July to October), 40% (November to December), and 127% (March). Thus, in the total square meters rented in both years mentioned, 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 figures such as 13 900 m^2 in March. In the first 4 months of the year, about 65% of all rented space from the previous year has already been rented. Thus, growth percentages are marked comparing the year 2022 with 2021, of 80%, 94%, 138%, and 363% for January through April, respectively. As it can be seen by looking at graph 5.16, the peak months for this space requirement usually start near the summer (July) and goes through the end of the year (November, December).

Some estimates made by the Supply Chain Space Team show that until the beginning of summer (June) there will be a need to rent around 15 000 m^2, with an ever-increasing tendency for the hottest period of the year, as it is possible to see the correlation between previous homologous times, in graph 5.17, and also observed previously in the number of stored products presented in Chapter 4, section 4.4.

As expected, following graph 5.17, as the m^2 rented increases, the costs follow the 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 (where the containers arrive) 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, check/audits, among others. Another cost, not included in the graphs, of only having one counterbalance forklift with clamps for all external warehouses, inserting the constant need to be transported in order to unload and load trucks.

However, the thought should always be: the more square meters needed, the higher the rental cost, the higher the handling, and consequently higher the number of transportation executed, since the products

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[6] For the first two months of this year, the space was leased to a different outsourcing company and no records were kept of the m^2 reserved during that period.

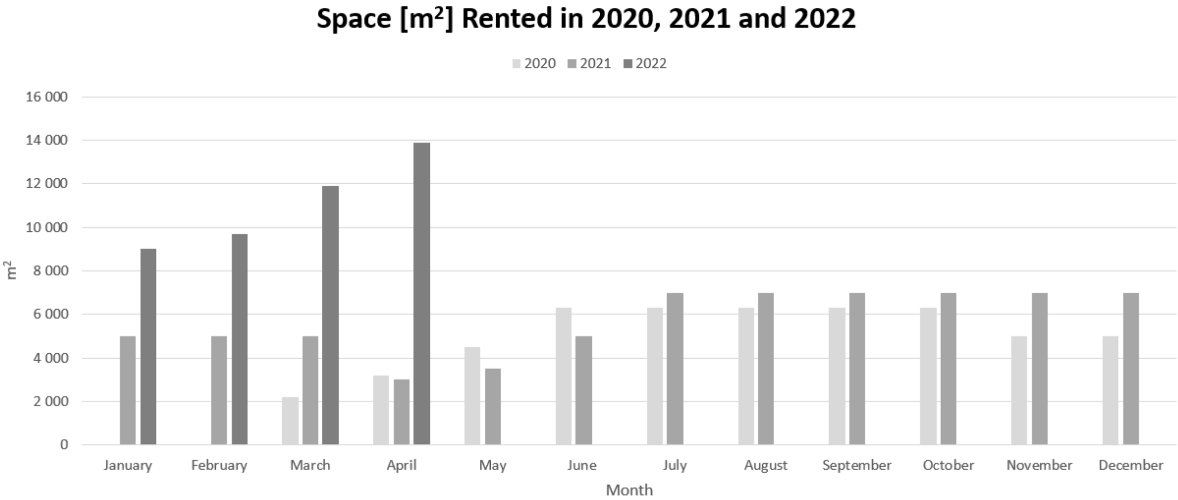

Figure 5.16: Space [Square Meters] Rented in 2020, 2021 and 2022

are only dispatched from Plaza II. Therefore, even if they are sent directly from the port to the rental warehouse, to follow the sales flow, they always have to be sent to the central warehouse, to be shipped and invoiced according to their destination.

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 increase, 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 breakage aspect, because the more movements the product experiences, the greater the probability of it suffering some kind of damage that results in its impossibility to be sold, without any return of that value.

5.4.2 Design of the New Structure

After deciding on the type of structure and system that should be studied, the first step was to understand, among the six initial suppliers in Portugal, which ones would be able to supply and satisfy the project's needs in constructive terms. Another important factor was also the company's ability to develop a project of this size. Thus, after a new contact, only three of the six companies[7] showed availability to visit the central operations warehouse in Azambuja. During each visit, vital information was collected for the development of the project, and doubts were also raised on the construction site. After the three visits to the warehouse, the following points were verified.

The first supplier, who had already sold storage structures both to Worten and to other Sonae sub-

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[7] The names will not be revealed at the request of both the external companies and Worten, since the project is still under viability study at this stage.

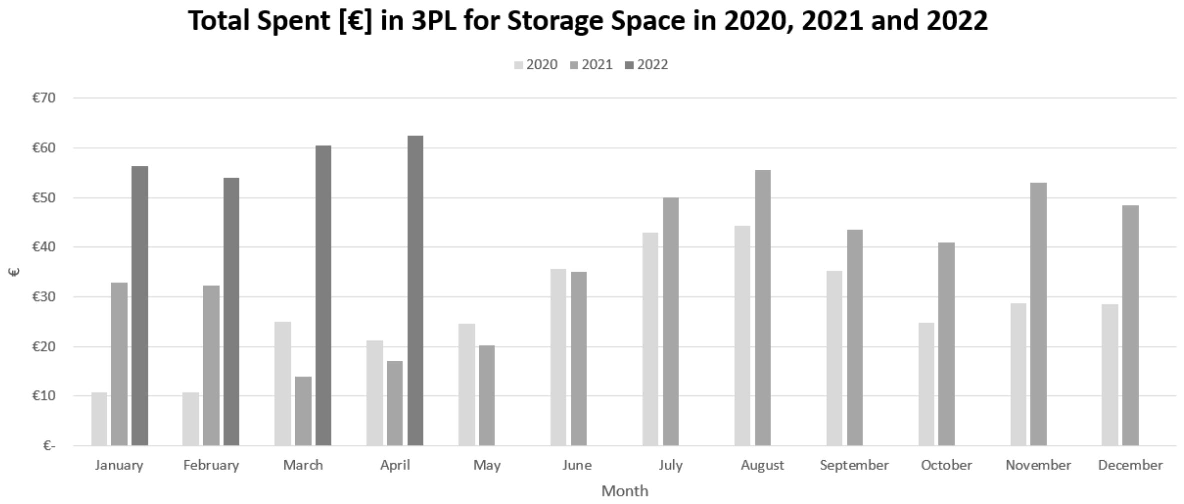

Figure 5.17: Total Spent [€] in 3PL for Storage in 2020, 2021 and 2022

holdings, would not be able to meet the space's needs. This was because this company only had prefabricated metallic structure modules, in which at most each platform could have length and width dimensions (6x5)m, which would require the implementation of hundreds of platforms to meet the requirements, and then these also could not support more than one level of appliances on top (i.e., applying only a stacking factor of one). It also made operation on top of the platform impossible, as you could not use electrical equipment due to the capacity of the structure, and you could only move the products with equipment like a hand pallet truck.

When it occurred the visit to the second supplier, this one with a wider constructive range and also with several mezzanine based projects in its portfolio, the author was able to discuss several needs. However, the most important, which is the feasibility of having a counterbalance forklift with clamps (see figure, 5.3) working on top of the platform was not possible, due to the weight of its moved load and the equipment itself. So this second supplier was able to provide a platform for the desired floor area in its entirety, with the ability to stack the various appliances high. This structure would be metallic, covered with three layers of solid wood, and on top, of the area in contact with the equipment, a metallic floor called ”olive leaf plate” would be used. From a long-term point of view, there were also several technical problems with the application of wood, due to the constant movement of the products and their weight, wear and tear would be evident, requiring continuous and constant maintenance over time. Therefore, this also became a non-viable solution for the space.

A visit was then carried out with a third supplier, this one from a construction company in Maia, Porto. It was then quite clear, that for the realization of the project so that it had all the robustness and safety necessary, the construction of the platform would have to pass through the application of concrete. This solution, although fixed, can meet all the requirements of the project. From the operation of a counterbalance forklift with clamps to the lifting of products with very high weights and at various levels. This would be a replication in a way in terms of the construction of a Mezzanine that the warehouse already has today, on a smaller scale, which has all the operations of small but high-value products.

A meeting was then held with the company's Flow Engineering Team, where the decision was made for the reasons explained above that the only supplier capable of supplying and developing a project of this size would be the third and final one. Thus, several meetings were then held with the supplier in which all the needs of the project were discussed, both in operational terms (on the Worten side) and in constructive terms (on the supplier side), to always follow the needs of the company and its operation. The results of all these meetings, as well as the cost of each parcel needed to develop a platform, are detailed in 5.4. An even more detailed price breakdown for the application of concrete and formwork can be found in appendix C, table C.1. Further details also on the lighting and fire network (contemplating underneath and above platform) can be found in, table C.2, [76], and table C.3, in the same appendix.

The budget 5.4, shows seven columns that incorporate: the project area of the parcel, description of the expense, units used in the calculations, quantities needed of each point, cost per unit (when possible, there are matters in which only a total package cost is contemplated), total cost incorporating the units needed, and in the last column, what percentage of that point is cost-wise in relation to the total budget. The value presented for the construction of the platform is in the penultimate row of the table, 1 733 978.52€, and as the project will not be adhered to, this may suffer increases due to price fluctuations of both labor and raw materials, up to about 20% of the previous value. Afterward, this budget, if it is later decided by Worten to proceed with this investment, would have to be redone and reanalyzed. This Master Thesis aims to be the starting point for the development and construction of a highly efficient storage structure for the space under study.

Considering the (real) costs reflected in the graph, 5.17, it was performed the calculation of the Payback Period, as explained in chapter 3, section 3.4.2. The value given to the 'Net Investment' part, was the value presented in the budget already with the percentage of price increase (always taking into account the worst case scenario), 2 080 774.22€. The value for the 'Average Annual Operating Cash Flow' was the average total cost over 5 years paid to rent the respective external storage spaces. The formula 5.42 was calculated. As analyzed earlier in graph 5.17, these values have shown a successive increase over the same period and so it was decided to use a growth approach, extrapolating the rental values both for the remaining year 2022 and for the years 2023 and 2024. This reasoning will be explained below.

$$\mathrm{PP} = \frac{NetInvestment}{AverageAnnualOperatingCashFlow} \tag{5.42}$$

Looking now at the Return on Investment, equation 5.43, for the investment in question with a long term view, this should be considered not for one year, but for 5 years. The numerator 'Net Benefits' is the gain obtained minus the amount invested. The gain over a time horizon of 5 years is the sum of the costs of renting external warehouses that the company incurs over this period. The amount invested is the value of the budget presented in table 5.4, always considering the worst case scenario (highest value), 1 910 086.99€. The denominator, ”Net Costs”, corresponds to the cost of the investment itself. Multiplying by 100 gives the percentage of return after 5 years.

$$\text{ROI} = \frac{NetBenefits}{NetCosts} \times 100 \tag{5.43}$$

The values obtained for the Payback Period and Return on Investment are in table presented 5.3, 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 5.3: 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%

Analyzing now, the values obtained in table 5.3. It is possible to observe that for any growth percentage considered, the investment is highly profitable from the financial point of view, since all the values for the PP are lower than 2.6 years, and also all the results concerning the ROI are higher or almost 100%. This means that evaluating the investment in the long term, considering 5 years of analysis, in the worst case, 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 first month of the year 2020, today, there would only be 1 months left for it to be paid in full (June 2022).

5.5 Summary of Chapter 5

The present chapter, chapter 5, is both an analytical and experimental approach to the problem addressed in this master thesis. The chapter begins with section 5.1, giving a detailed description of the reasoning for having achieved the current layout, such as its detailed physical spatial characterization, highlighting the number of locations in the solo area, as well as space-relevant measurements. This was a starting point to allow for some considerations made in the sizing of the new structure.

Moving on to the next section, section 5.2, the two structural options for the space were explained: push back system and platform, as well as why only the second option was pursued and further developed.

Table 5.4: Total Project Budget for the Construction of a Logistics Platform at the Company's Central Operations Warehouse, Worten

Project Area	Expense Description	Units	Quantity	Cost per Unit [€]	Total Cost [€]	%
Formwork	Pillars	m^2	230,40	20,00	4 608,00	0,29%
	Platform	m^2	17 787,97	22,00	391 335,29	24,59%
Concrete	Concrete C25/30 S3 D22 CL0,2 PAV XC2(P)	m^3	3 558,98	79,00	281 159,16	17,66%
	Labor for Concrete Application	m^3	3 558,98	5,00	17 794,88	1,12%
	Pump Displacement	un	5,00	75,00	375,00	0,02%
	Line Assembly	ml	50,00	9,00	450,00	0,03%
	Pumping Service	m^3	3 558,98	9,50	33 810,28	2,12%
	Execution of Compression Tests	un	20,00	20,00	400,00	0,03%
	Steel Rod and Armorer's Labor	kg	337 611,24	1,50	506 416,86	31,82%
Perimeter Security	Set of Stairs	un	2,00	3 000,00	6 000,00	0,38%
	Platform Gate	un	3,00	364,28	1 092,84	0,07%
	Perimeter Containment Structure	m	541,42	300,00	162 426,00	10,20%
Project	Licensing and Design	-	-	-	25 000,00	1,57%
	Supervision and Work Follow-up	-	-	-	20 000,00	1,26%
	Safety/Quality/Environment Guarantee	-	-	-	10 000,00	0,63%
Fire & Ilumination	Fire extinction network	-	-	-	21 584,00	1,36%
	Ilumation on top/underneath platform	un	-	-	18 327,00	1,15%
Equipment & Man Power	Counterbalance forklift with Clamps	un	1,00	55 000,00	55 000,00	3,46%
	Auto-crane to put the forklift above the platform	-	1,00	400,00	400,00	0,03%
	Extra Labor Man Power	for 2 shifts everyday, 5 years	2,00	17 779,92	177 779,20	10,25%
Total Project Costs					1 733 978,52 €	
Total Project Cost Including Possible Price Increases (20%) Raw Material and Labor					2 080 774,22 €	

After informing the reader of the system to be adopted in constructive terms, a characterization and design of the operational flows that will change with the implementation of a platform/mezzanine is made, section 5.3.

Once the solution was well defined, the next step was to develop a space simulator in Excel, which is the basis of analysis for this master's thesis. This simulator has a database that incorporates all the stored stock of big-sized appliances in the 701 solo area, in the year 2021. Ten simulations were performed here to simulate various scenarios and to understand which output is most advantageous for the selection of the optimal platform height. This optimal height aims to optimize the bottom part of the platform as much as possible and to have an upper part that allows a substantial increase in square meters, for no, or less dependence on external warehouses. It was then concluded that the most optimal height and that favored more flexibility and operational advantages would be with the INPUT of 4.5m. Assuming this value for INPUT, the platform useful height to store big-sized appliances either underneath or above the platform are respectively, 5.1m and 4.9m.

To conclude the chapter, the last section, section 5.4 is dedicated to costs, and in the first phase, the costs of the current scenario were evaluated as well as what they entail for the company in terms of expenses. The basis of these figures consists entirely of the rental of external warehouses, of which there are already three to date, excluding the central operations warehouse. In a second phase, the investment in the new structure was evaluated, based on financial indicators such as PP and ROI. Observing the calculated values it was determined in how many years there would be a return on investment in monetary terms (worst case scenario): 2.52 years, as well as what the percentage of return in five years costs: 98%. The finance and operational viability of this project will be discussed in the next chapter 6.

6. Results Discussion

This penultimate chapter devoted to the discussion of results is divided into three sections. The first reflects on the financial indicators. The second considers the space gains and operational aspects regarding the implementation of the designed structure and provides the company with a final suggestion for approaching the problem. Finally, in the third section, the limitations of the tool designed as the basis for this master thesis are discussed.

6.1 Financial Indicators

This chapter aims to perform a general analysis of results, namely regarding the feasibility of the project, its implementation and possible limitations. Thus, starting with a more mathematical and concrete part, the two indicators evaluated in chapter 5, section 5.4.2, PP and ROI. PP allows the company to understand how long it would take to pay off the investment, taking into account the costs that would be saved by advancing with the project. The ROI represents the annual percentage within the PP that will give that return on investment. Both indicators can be calculated through each other, ROI is the ratio of unit value one to PP, and PP is the ratio of unit value one to ROI. Regarding PP, it should be as short as possible, and investments with short PP are the most attractive, because getting back the money that was invested in a certain project should happen as soon as possible. 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. Given the calculated value of 2.52 years (highest scenario value), and in view of the operational horizon, this is an extremely feasible investment, as it allows a doubling of the current space, in order to keep the operation centralized in a single location. PP is widely used because it has a very simple method of calculation, this simplicity makes it possible to analyze the reliability of the project. However, this indicator does not contemplate the time value of money, due to the fact that money received sooner is worth more than the one coming later, entering in the equation the possibility to invest and earn even more. Additionally, not all cash flows is considered, it only considers cash flows up to the date of the project and not possible future cash flows. The possibility of the project becoming unenviable after the payback period (stopping all cash flows). However, PP is a great preliminary screening tool for projects that do not satisfy payback criteria of not going any further due to their infeasibility. When approaching ROI indicator, 98% in 5 years. The higher the ROI, the better the type of investment or project, because we are getting a higher percentage of profitability as well. However, as in the case of PP, it depends a lot on the type of project to be able to draw solid conclusions regarding this indicator. For there are many trade-offs and this is becomes more solid when compared to other projects. The most significant benefit of using this last indicator is that it is a simple mathematical formula to compute and comprehend. It refers to profitability and it is not misunderstood because it has the same meaning in all possible contexts. However, 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 important to make all trade-offs, even those that are not directly reflected in cost reduction for the company, but that provide clear advantages for a more sustained and centralized operation.

6.2 Space and Operational Necessities

The points that will be raised moving on this results discussion chapter are going to be comparisons of the system as is, considering today´s company needs and the meeting of these necessities with the design of the new platform structure, for the 701 solo area.

After planning the structure (section 5.2), several analyses and ten simulations were performed on the designed simulator (section 5.3), it was concluded that the most advantageous height for the space under study would be for the platform to have an INPUT value of 4.5m. 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 a doubling of the current space, being possible to store 8 513.39 m^2, and with this project, it will be possible to store 17 026.78 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, of around 25% of the space. In April, the company had the need to rent around 13 900 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 5 386.61 m^2. This allows us to conclude that although the platform can mitigate this need for outsourcing space, it will not eliminate it entirely. To conclude this line of thought, considering the extra gain of space and the cost of the investment, Worten would pay about 244.80 €/m^2 today to implement this solution.

Therefore, this thesis suggests to the company under study, Worten, that the possibility of carrying out a segmentation of the supply chain and flow operation be 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 satisfied for probably the next decade, this solution will have to go through a division in terms of warehouses of the flow of small domestic 708, and large domestic 701. Carry out a procurement of a large space near the current warehouse, acquire it on the basis of similar contracts to the current warehouse, implement the present platform project while there is no operation of any kind in that area, and then transfer all the products, and build a second warehouse targeted at large domestics. 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 specialization of the space, the operators working in each of the spaces could also be fully trained, allowing them to have qualified people, also reducing the probability of breakage and damage to products internally and increasing the productivity and efficiency of the entire operation itself. This suggestion comes from the fact that the solution found 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 if the necessary suspensions are not made. Immobilizing an operational part, even for a day, let alone a month, has an astronomical cost for supply and order fulfillment. Added to this is the fact that the space must be emptied, even if in stages, before the structure can be built. 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. It should also be noted that if this solution is chosen by the company, of segmenting the operational flow, and looking for a second warehouse, then implementing the platform structure, this entire project has to be redesigned in view of the new location, serving as a solid study base. This project does not lose viability by acquiring a new permanent space, because an efficient storage of a large domestic will always go through a block stacking system as it is done nowadays.

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.

6.3 Warehouse Space Simulator Limitations

Finally, it is necessary to mention the limitations of the simulator built as a tool to analyze the project outputs. The limitations pass through essentially three points. The first point is the fact that the simulator database depends 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 not including January 9th and 10th, April 25th, 10th and 28th of October due to failures. It would be important here 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 very 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 only a tool for 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 future work, explained in the next and final chapter, chapter 7, section 7.2.

7. Conclusions and Future Work

The present and last chapter of this master's thesis, has as its first objective to present in a very summarized way the macro conclusions of the project, and the milestones reached in terms of analysis. The second objective presents which points of study regarding the present challenge that can be continued in the future and how it can add value to Worten.

7.1 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 master's thesis, an entire case study of the company in question was carried out (see chapter 2), detailing all the macro and micro operations relevant to the project, as well as explaining the challenge proposed by the company and its objectives. Next, extensive and detailed research was done in chapter 3, on what types of storage are most commonly used for larger products, and also for big-sized appliances. When this learning about the theme was completed, very focused on articles from the scientific community, magazines, other documents present in the research platforms, it was started the understanding of how it would be possible to solve the company's problem, always having in mind the most efficient solution and that presents feasible investment values by Worten. After studying several options, two options remained for future discussions within the flow engineering team, and it was decided, after performing the trade-offs of the two possibilities, as presented in chapter 3, to move forward with the idea of the platform. From this point on, the way forward was mapped out, presenting a methodology for the development of the project, starting with a complete analysis of the warehouse data, from receipt, to storage, to shipping, chapter 4. The project 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, taking into account all categories and subcategories of the wide range of products that are stored today in the area to intervene, 701 solo (see chapter 5). It was then supported with the execution of ten simulations and the analysis of several trade-offs that the optimal height of INPUT of the simulator would be 4.5m (see chapter 5). However, as discussed in chapter 6, the best decision to be taken would be to build the platform in the short term, requiring a substantial initial investment, but with the operating expenses to date, it would pay for itself between 2.52-2.34 years, presenting gains also varying from 98%-113% in the end of the fifth year, respectively. 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 the Space Warehouse Simulator, no simulation was performed by increasing product quantities beyond what was effectively stored in the year 2021 because it was not the objective intended by the Worten with the development of this tool, for the purpose of this master's thesis. It would be unrealistic to test different quantities scenarios for 1 890 locations with distinct typologies/requirements, in approximately 365 readings, as the simulator data base structure uses as main key *Location_Item*, related with several variables.

7.2 Future Work

Always with an eye to the future, and what it can be done today to improve tomorrow, there are essentially two points worth mentioning in this concluding chapter.

The first point is related to the tool developed, the simulator. As of today, it only incorporates data from 2021, and space possibilities, always taking into account the stock that was actually stored last year, 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, reflected in the average percentage of occupancy and free area. The implementation of this tool would be an added value both for the management part done by the flow engineering team and for the top managers to be able to follow the results graphically, week after week. Since at the moment there is no support in terms of software or programs for the daily monitoring of this theme.

The second point already raised but very important to also be mentioned here, is in case Worten opts for the suggestion made earlier to expand operations to a second specialized warehouse for big-sized appliances, through the construction and implementation of the structure idealized in this master's thesis, this serves as a basis and model, however the values will have to be recalculated for the space to be, adding at that time also the stock readings made of the 701 solo are related to storage in 2022, in order to make the data even more reliable, always following the current needs of the company.

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A. Supplementary Images to Chapter 2: Worten Case Study

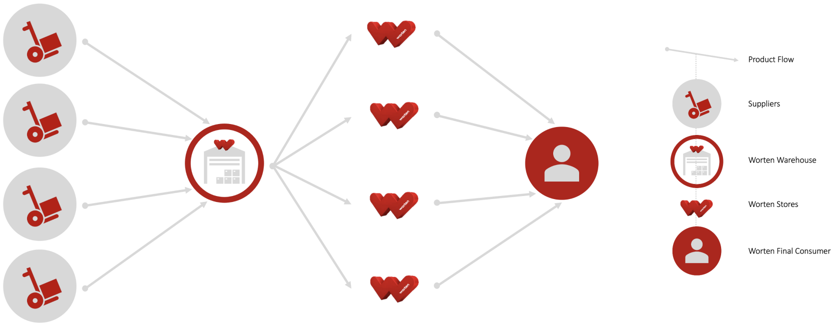

Figure A.1: Supply Chain as It Was

Figure A.2: iLPNs placed on reception process, on the left PBS and on the right Long Tail products

Figure A.3: Solo Space Overview in the Warehouse

General Flow Diagram[1] of Worten Warehouse:

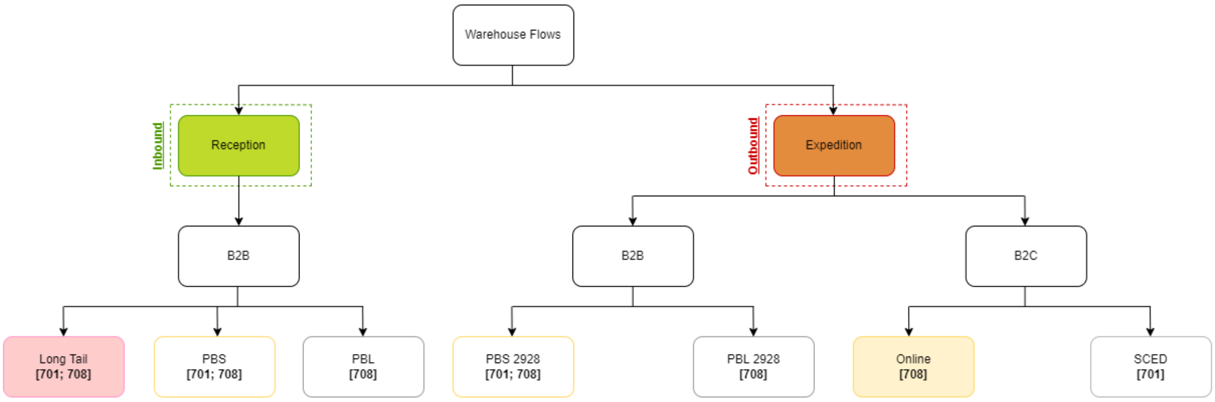

Figure A.4: Diagram of the Warehouse Flows in a Macroscopic view

Flow Diagrams´ of 701 Activities:

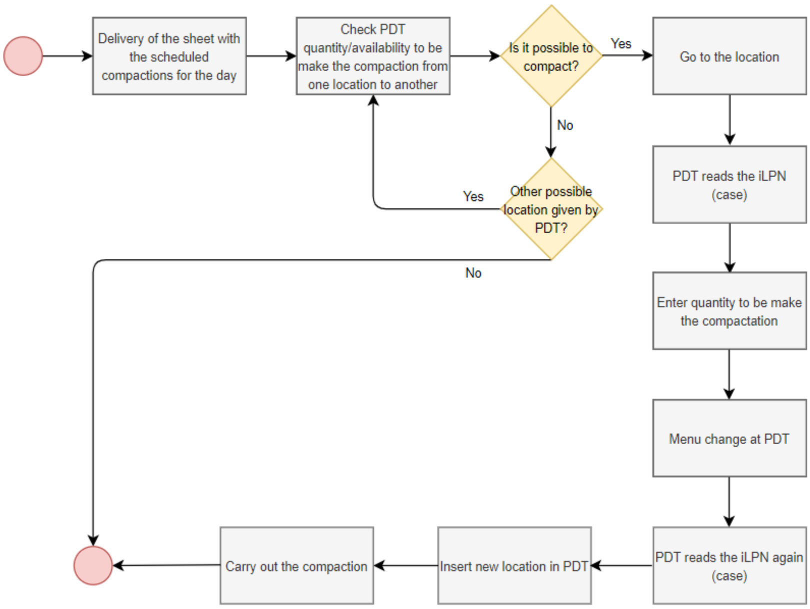

Figure A.5: Compact Flow on 701 Area, using *draw.io* program

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[1] All the flow diagrams relating to the intervention processes of the study area were drawn up with the help of the *draw.io* program.

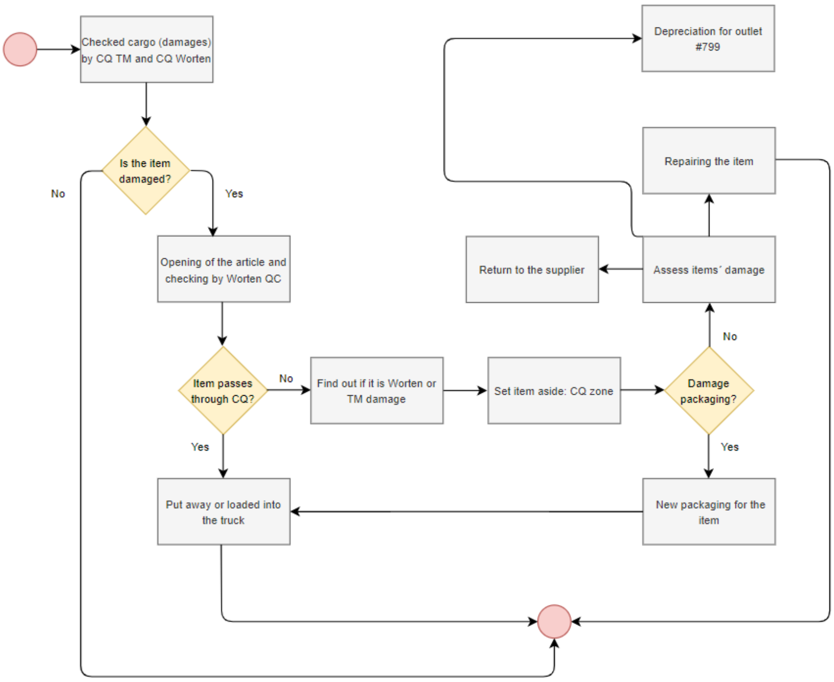

Figure A.6: Quality Control via SCED Flow Diagram, using *draw.io* program

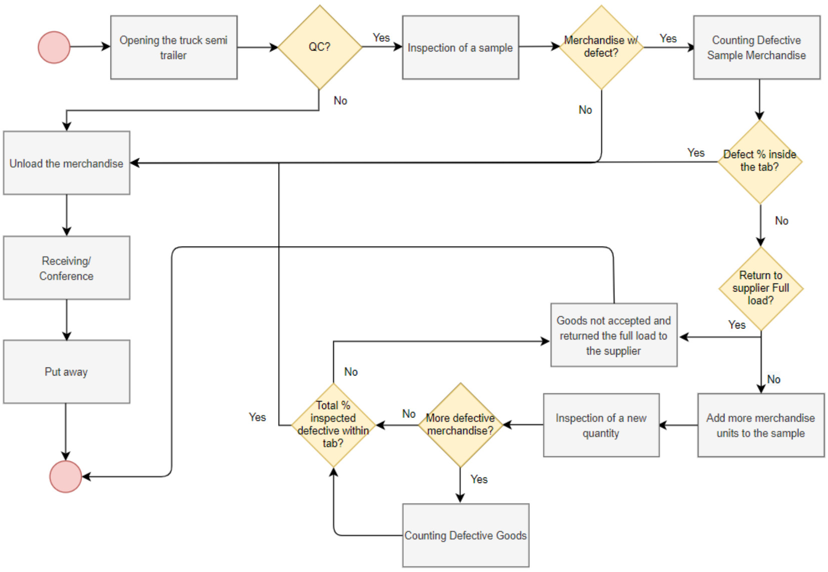

Figure A.7: Diagram of the Unloading Operations, using *draw.io* program

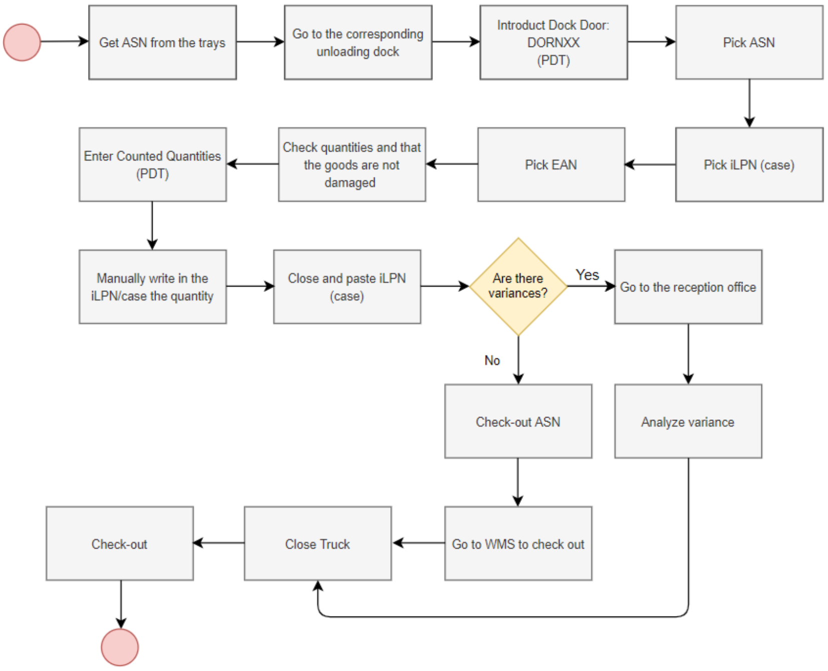

Figure A.8: Diagram of the Check/Reception Process, using *draw.io* program

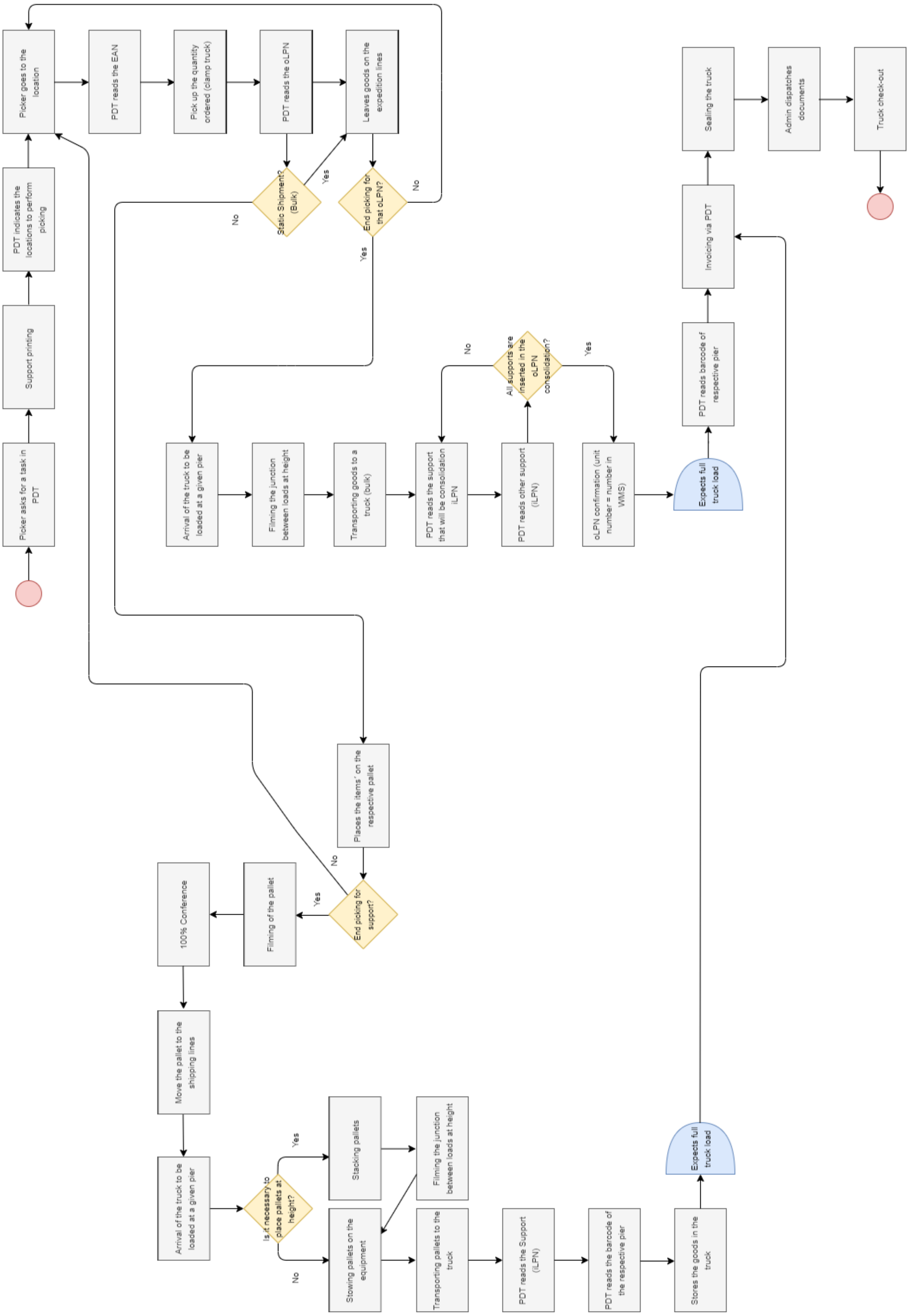

Figure A.9: Expedition Flow PBS, using *draw.io* program

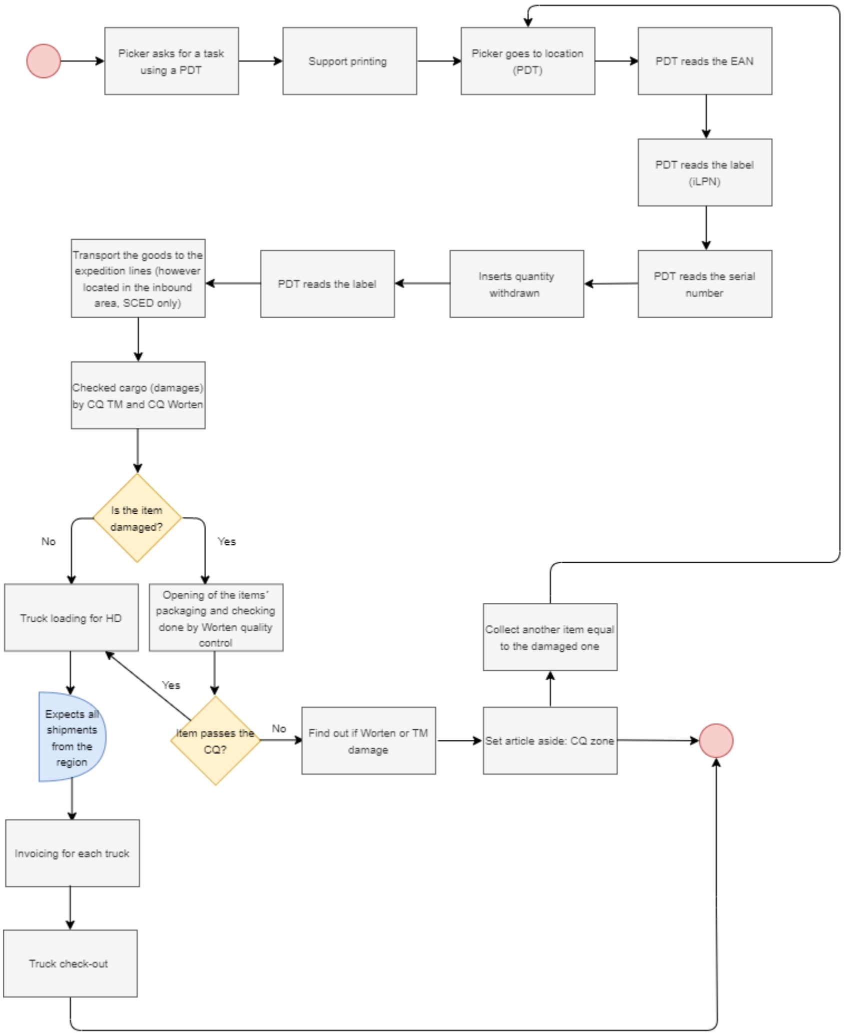

Figure A.10: Expedition Flow SCED, using *draw.io* program

B. Supplementary Images to Chapter 3: Literature Review

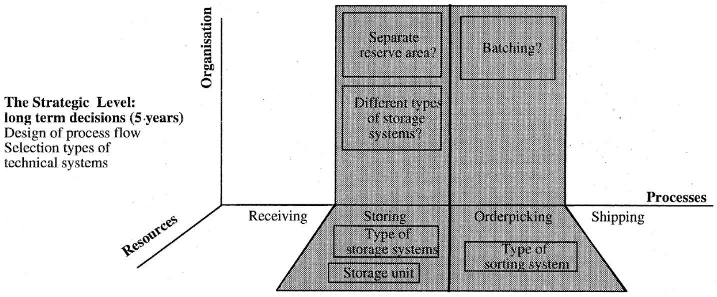

Figure B.1: Strategic Level, [1]

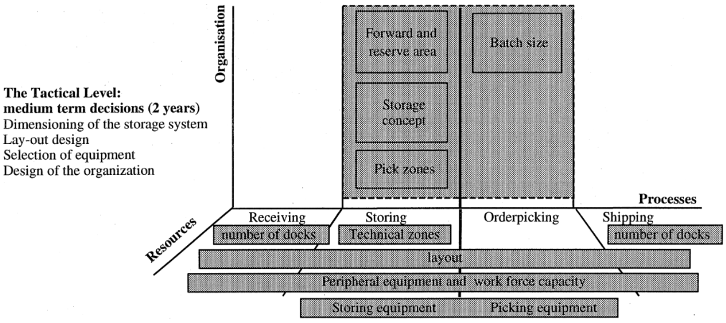

Figure B.2: Tactical Level, [1]

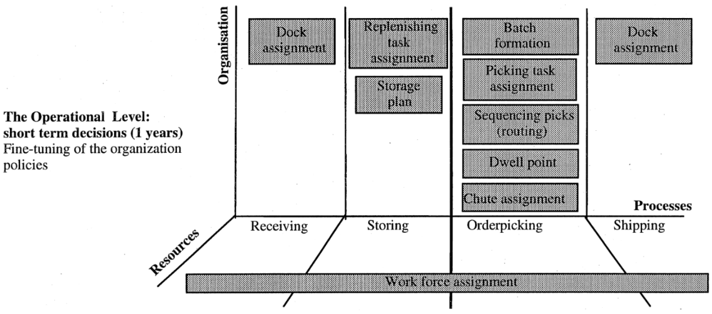

Figure B.3: Operational Level, [1]

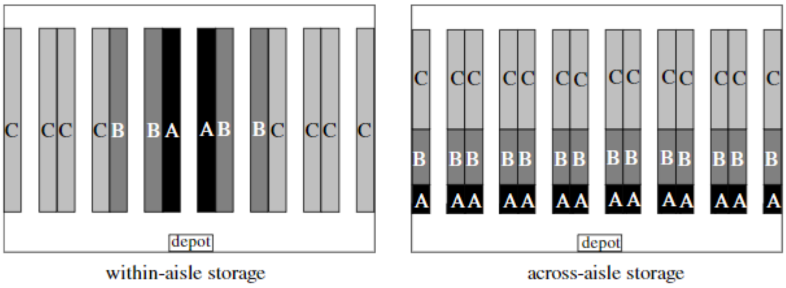

Figure B.4: Visual explanation of two used manners to implement class-based storage, [2]

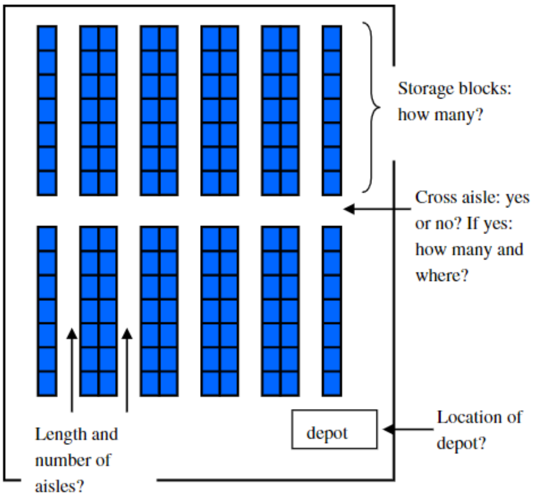

Figure B.5: Layout thinking decisions in a design of an order picking system, [2]

Figure B.6: DIN/Drive-through Racking Structures, [3]

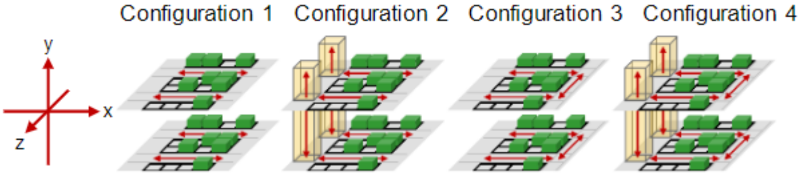

Figure B.7: Satellite and Shuttle possible configurations, [4]

Figure B.8: Satellite and Shuttle Structure Example, [5]

Figure B.9: Push-back System, [6]

Figure B.10: Adjustable Pallet Racking, [7]

Figure B.11: Narrow Aisle Racking, [8]

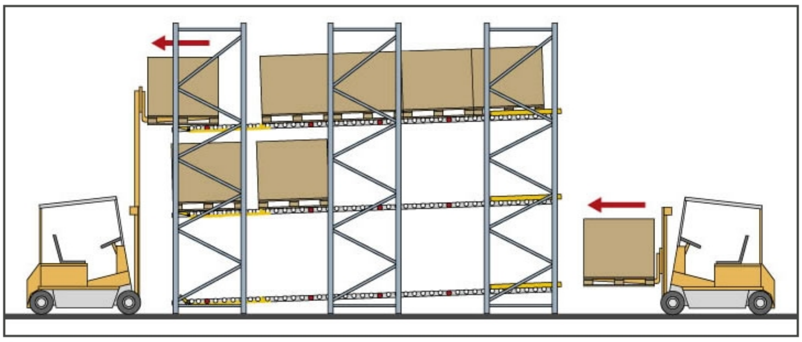

Figure B.12: Gravity Flow Racking, [9]

Figure B.13: Platform System, [10]

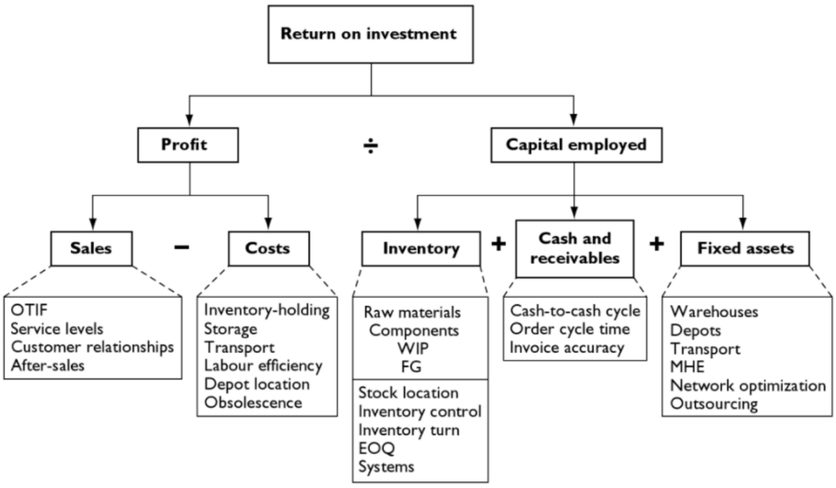

Figure B.14: Examples on how ROI can impact a logistics' organization, [11]

C. Supplementary Images to Chapter 5: Design Development

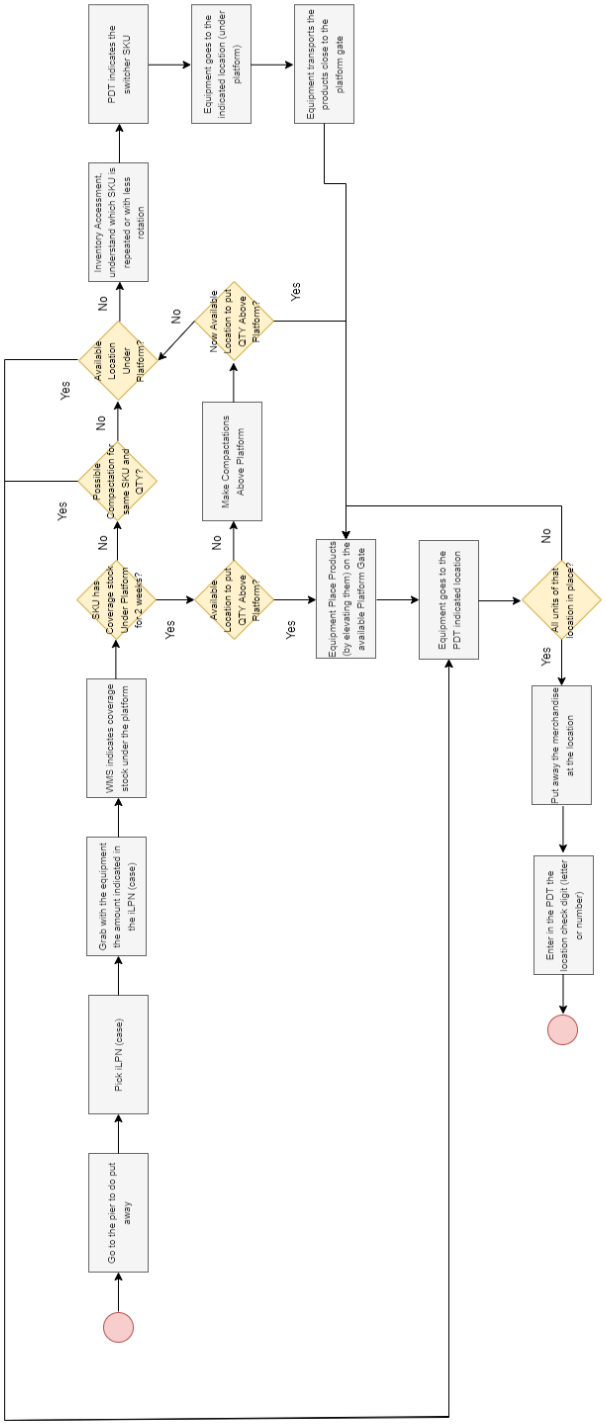

Figure C.1: New Flowchart of the Put Away Activity, using *draw.io* program

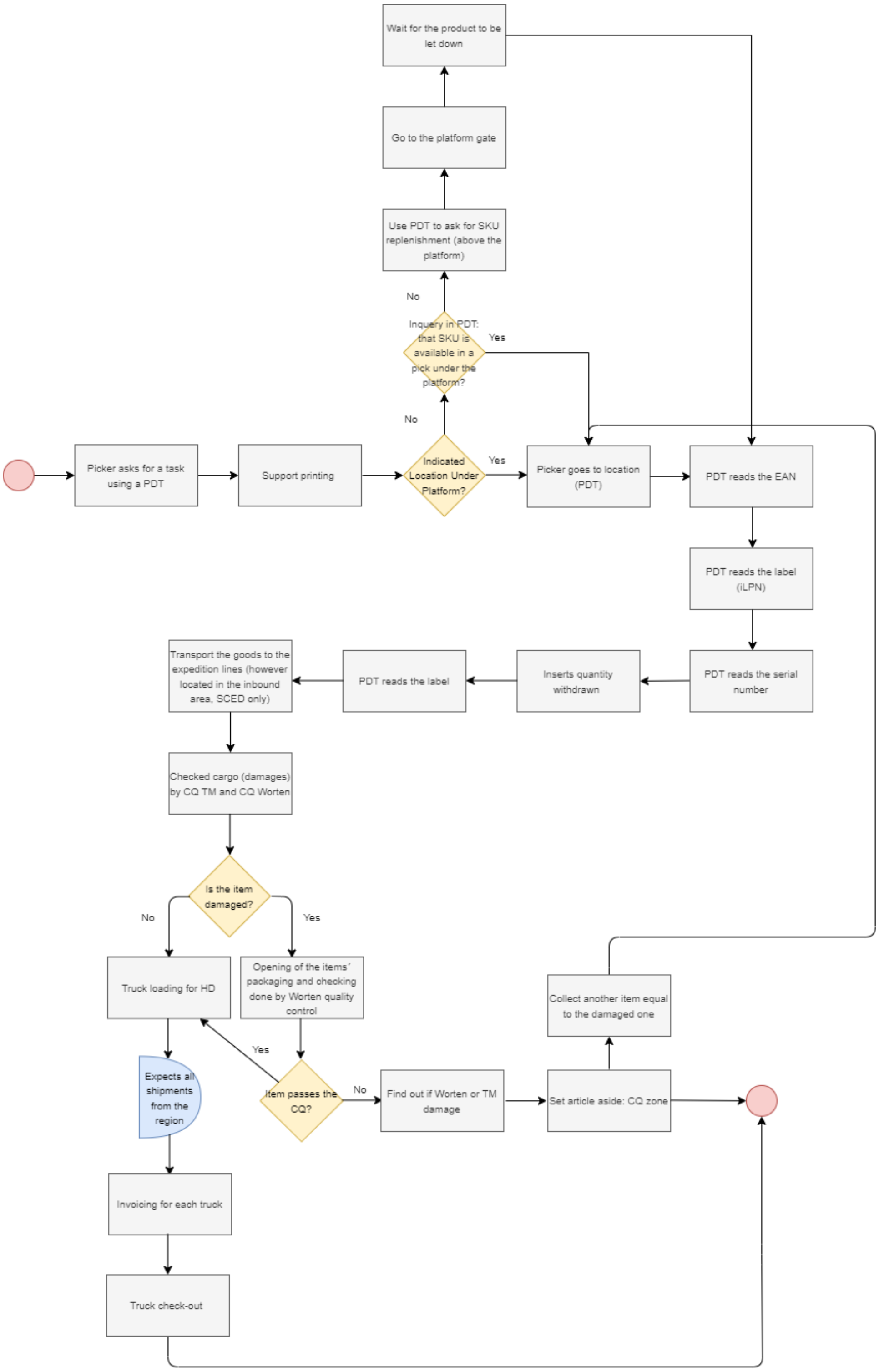

Figure C.2: New Flowchart of the PBS Picking and Expedition Activity, using *draw.io* program

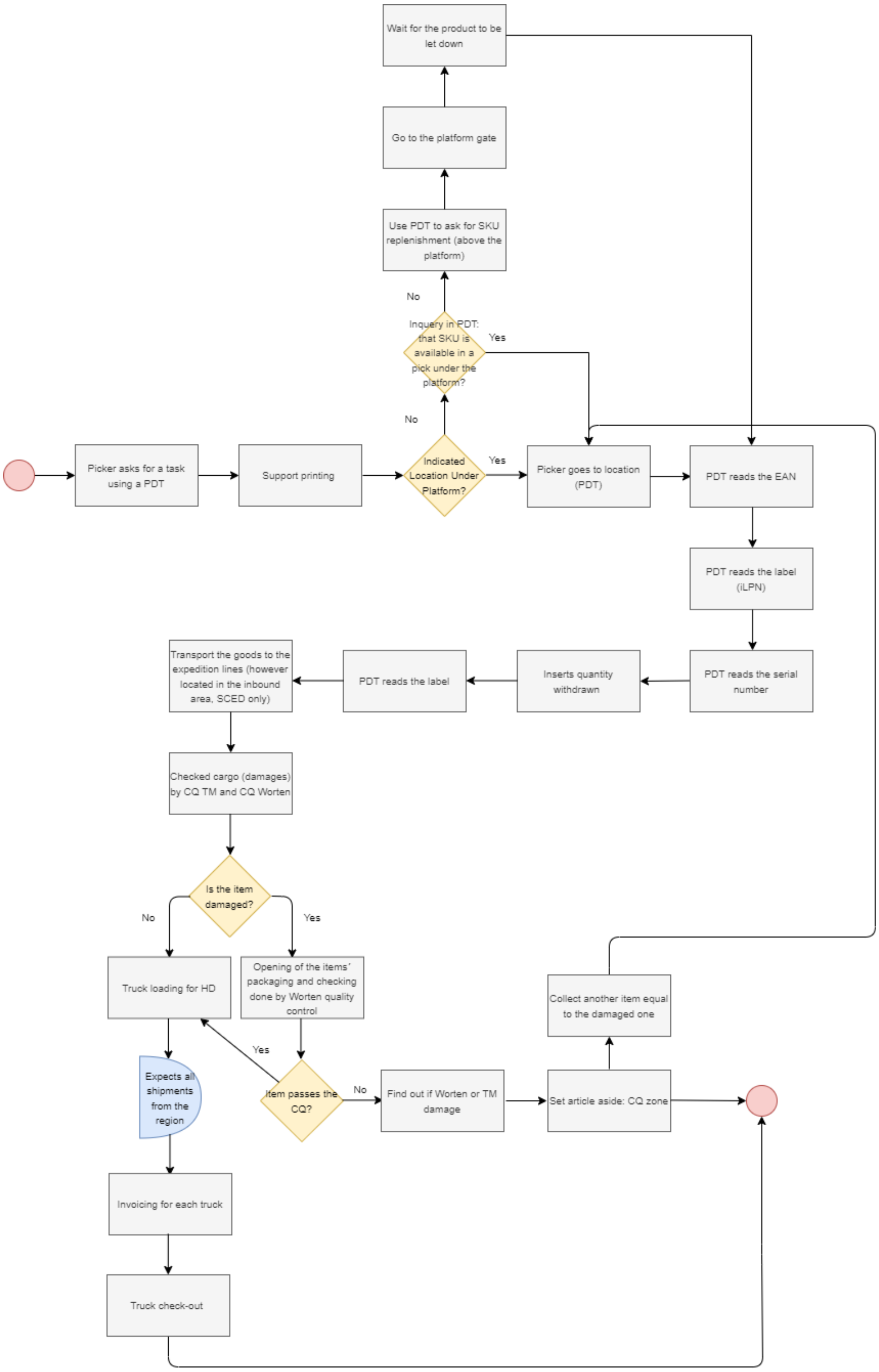

Figure C.3: New Flowchart of the SCED Picking and Expedition Activity, using *draw.io* program

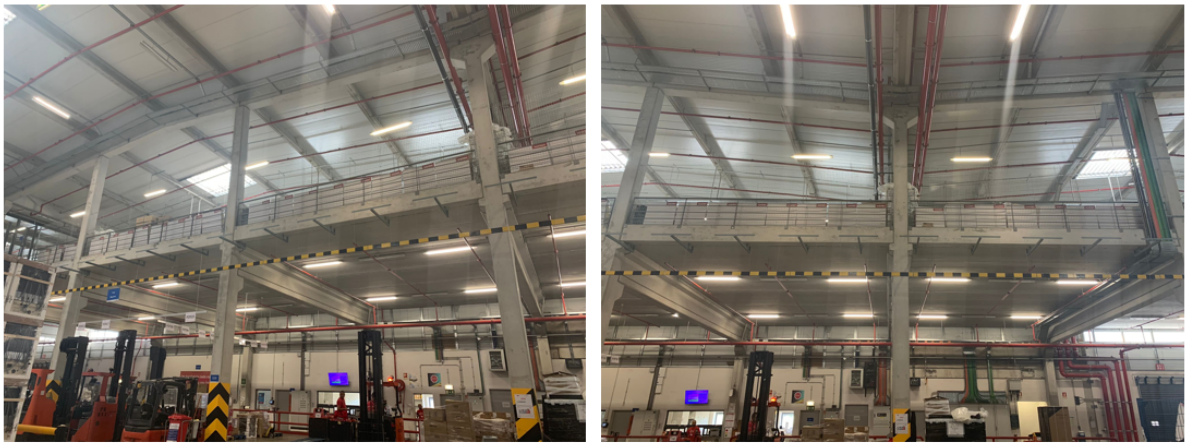

Figure C.4: Platform/Mezzanine in Worten Warehouse

Table C.1: Specific Calculations Regarding the Measurements for Concrete and Formwork Required

				Width [m]	Lenght [m]	Height [m]	Elements Number	Quantity
Measurements	**Concrete [m3]**	Pillars		0,40	0,40	4,50	32,00	23,04
		Platform	Fund	110,03	160,68	0,20	1,00	3 535,94
			Side	110,03	160,68	-	-	0,00
	Formwork [m2]	Pillars		0,40	0,40	4,50	32,00	230,40
		Platform	Fund	110,03	160,68	-	1,00	17 679,68
			Side	110,03	160,68	0,20	2,00	108,28

Table C.2: Total Budget for Two Illumination Networks Including Above and Underneath the Platform

	Units	Quantity	Cost per Unit [€]	Total Cost [€]
Cable FVV 3G1,5MM	m	1490	2,50 €	3 725,00 €
19504 Tape LED 220V 12W 2835 120SMD	m	745	6,50 €	4 842,50 €
Watertight Derivation Box	un	75	8,00 €	596,00 €
Total for 2 Illumination Networks (above and underneath platform)				18 327,00 €

Table C.3: Total Budget for Two Fire Extinction Networks, Considering Above and Underneath the Platform

		Units	Quantity	Cost per Unit [€]	Total Cost [€]
Supply and laying of medium series galvanized steel piping, with threaded fittings, duly painted in the proper color, including fittings, elements for visible fixing on walls and ceilings and all supplies and complementary works, in the sprinklers network	Diameter of 80mm	ml	14	40	560,00 €
	Diameter of 65mm	ml	56	32	1 792,00 €
Supply and installation of sprinkler test and purge valves, including all accessories		un	35	160	5 600,00 €
Supply and installation of a sprinkler control station, including all the supplies and complementary works necessary according to the project		un	2	1420	2 840,00 €
Total for 2 Fire extinction Networks (above and underneath platform)					21 584,00 €

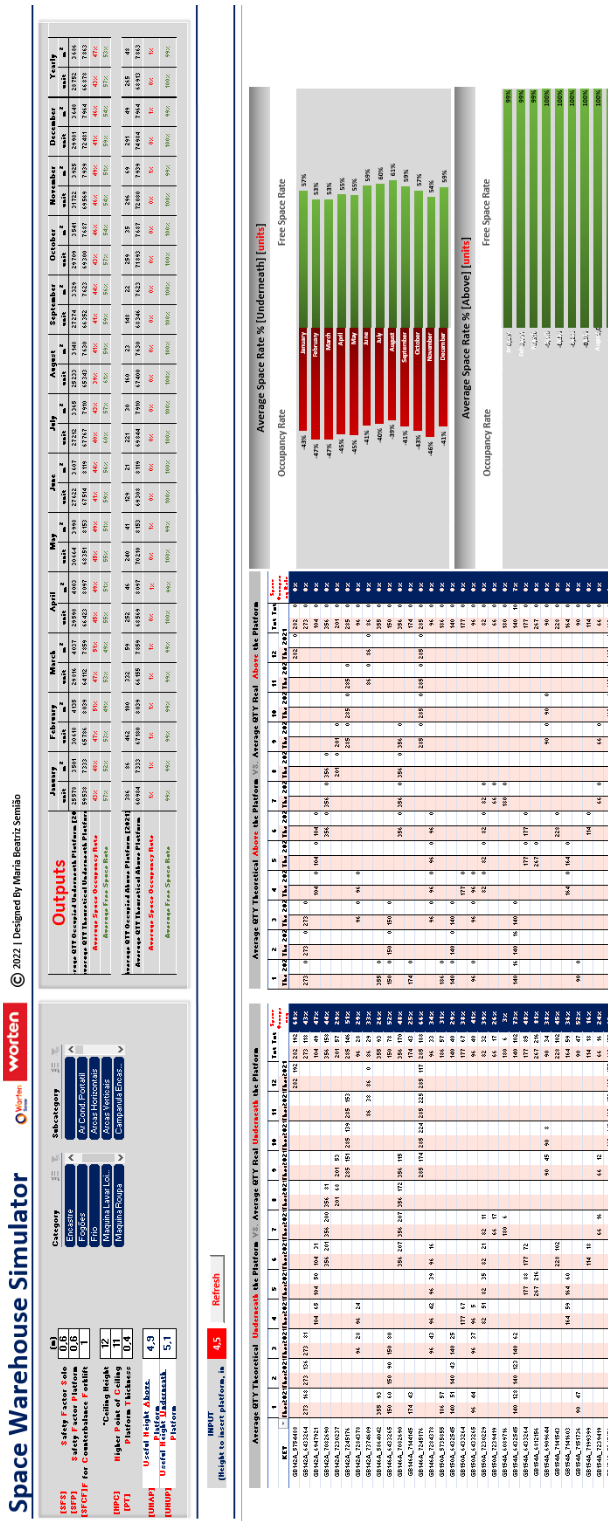

Figure C.5: Space Warehouse Simulator Overall Appearance