Improving warehouse operation flows

The Case Study of Worten

Afonso Manuel Mesquita Barroso

Dissertation to obtain the Master of Science Degree in

Industrial Engineering and Management

Supervisor: Prof. Susana Isabel Carvalho Relvas

Júri

Chairperson: Prof. Ana Paula Ferreira Dias Barbosa Póvoa

Supervisor: Prof. Susana Isabel Carvalho Relvas

Member of the Committee: Prof. Pedro Sanches Amorim

December 2019

Abstract

In the past years, the retail industry suffered constant evolutions mainly due to the growth of use and subsequent preponderance of the internet on our everyday lives. In Portugal, while smaller retailers struggle to face this change, the ones with higher financial power, taking benefit of economies of scale, were able to reduce prices. The market became then controlled by a lower number of competitors that, practicing similar costs between each other, focused mainly on customer satisfaction and buying experience, always pursuing to provide the best service level in order to achieve customer loyalty, retention and preference.

In this sense, factors such as the expected increase in demand, space restrictions, the higher range of different products offered and the constant need of reducing costs forced the necessity of redesigning warehouse layouts and operation processes. This dissertation aims to study and provide an alternative, reliable, efficient and profitable solution of the four main central warehouse operations of the Portuguese specialized retail company Worten.

In this dissertation, a brief introduction to the company is provided and the case study at hand is characterized along with the main business drivers that caused the problem. A literature review of similar case studies is developed in order to support the definition of a methodology to be followed in the simulation approach. Finally, the simulation results are presented and a critical analysis is developed before the conclusions and future work are drawn.

Key Words: Retailing, Logistics, Warehouse Management, Warehouse Design Layout, Simulation, Automation

Resumo

Nos últimos anos, a indústria de retalho tem sofrido uma constante evolução, evidenciada pelo crescimento do uso e preponderância da internet no dia-a-dia do consumidor. Em Portugal, os retalhistas de maior dimensão tiraram partido de economias de escala, permitindo-lhes praticar preços mais baixos do que os retalhistas tradicionais. O mercado passou a ser dominado por um pequeno número de competidores que, praticando preços semelhantes entre si e focando-se em fatores como a satisfação do cliente, a experiência de compra, a sua retenção e o melhor nível de serviço oferecido, controlam a maioria da quota de mercado.

Nesse sentido, o crescimento expectável da procura, as restrições de espaço, o aumento da variedade de produtos e a constante pressão para reduzir os custos, forçaram a necessidade de redesenhar *layouts* e processos operacionais de armazéns. A presente dissertação tem o intuito de propor uma solução alternativa fiável, eficiente e lucrativa para as quatro operações principais do entreposto da Worten, empresa Portuguesa de retalho especializado.

A dissertação inicia-se com uma introdução à empresa e explicação do problema em estudo e as suas causas principais. Posteriormente, será feita uma revisão da literatura existente no contexto de casos de estudo semelhantes, que servirá de suporte à definição da metodologia a adotar para resolver o problema em causa, que terá na sua base a simulação. Os resultados obtidos são apresentados e discutidos antes de se proceder à apresentação das conclusões finais e sugestão de trabalho futuro.

Palavras-chave: Retalho, Logística, Gestão de Armazéns, Desenho de Layouts de Armazéns, Simulação, Automação

Agradecimentos

Quero agradecer em primeiro lugar à Professora Susana Relvas por todo o acompanhamento que me deu ao longo de todo o trabalho.

Em segundo lugar, ao Eduardo Araújo por me ter dado a oportunidade de desenvolver este projeto na empresa.

Por último, ao Eng. Hugo Alexandre, em representação da Worten, por toda a disponibilidade e ajuda no desenvolvimento do trabalho.

Contents

List of Figures & Tables

List of Abbreviations and Acronyms

AGV – Automated Guided Vehicle

AS/RS – Automated Storage and Retrieval System

ASS – Automated Sorting Systems

B2B – Business to Business

B2C - Business to Consumer

BI – Business Intelligence

CQ – Quality Control (“Controlo de Qualidade”)

CSCMP – Council of Supply Chain Management Professionals

DW - Data Warehouse

EAN – European Article Number

EO – Express Operator

GRA – Big (“Grande”)

HD – Home Delivery

ILPN – Inbound License Plate Number

IO – Internal Operator

IOW – Improving Our Work

IT – Information Technologies

JIT – Just-In-Time

KPI – Key Performance Indicators

LAV – High Value Logistics (“Logística de Alto Valor”)

LI - Inverse Logistics (“Logística Inversa”)

MED – Medium ("Médio")

OLAP - On-Line Analytical Processing

ONL – Online

PBL – Pick by Line

PBS – Pick by Store

PEQ – Small ("Pequeno")

PIS – Pick in Store

PTL – Put to Light

PTS – Put to Store

PTW – Put Wall

PTZ – Put to Zone

RF – Radio Frequency

ROI – Return on Investment

SCED – Complementary Service of Home Deliveries ("Serviço Complementar de Entregas do Domicílio")

SCM – Supply Chain Management

SBS/RS - Shuttle-Based Storage and Retrieval System

SKU – Stock Keeping Unit

SPV – Post-Sale Service ("Serviço de Pós-Venda")

UTRAD – Repairment of Damaged Products ("Unidade de Tratamento e Recondicionamento de Artigos Depreciados")

WMS – Warehouse Management System

Chapter 1 – Introduction

In this introductory chapter, the problem background and brief overview of the problem at hand will be made. They are defined and explained the objectives and purposes that are aimed to be achieved followed by the presentation of the structure of this dissertation.

1.1 – Problem Background

The retail industry has been undergoing considerable transformations in the past years. The rise of the Internet and its gaining importance in our everyday lives, provided most of the population with knowledge that was previously much harder to obtain. Anyone, anywhere, anytime, with the simple use of a smartphone, not only can order whatever he or she wants but also is able to compare products and prices from multiple suppliers. In a market that was driven by a high degree of competition, mainly by the lowest price provided, this trend forced retailers to adapt to these new business drivers, such as service provided, lead times, product variety and quality, in order to differentiate from the competition and obtain customer preference.

Particularly in Portugal, this transformation led to the abandonment of small retailers that could not cope with market trends, prevailing the ones with high financial power that could take benefit of economies of scale. Customers have become more and more demanding and retailers pursue operating perfection, which requires breaking paradigms and reinventing the way this specific type of business is done.

This became a challenge for Supply Chain Managers, that found themselves in the position of optimizing at its maximum the logistic flows, both in terms of processes and operations in the shortest period of time possible. Worten, the company which the present work proposes to study, is the consumer electronics, home appliances and entertaining market leader in Portugal. The company intends to differentiate from competitors by offering the best value proposal for money, not only in the products sold but also in the services provided, establishing a close relationship of confidence with its clients (Worten, 2017).

In order to achieve this, a high operating efficiency and processes' coordination is required at the lowest cost possible. This work will be aligned with the improvement of the efficiency, both in terms of capacity and productivity, of the central warehouse of Worten, located in Azambuja, Portugal.

1.2 – Objectives

This Masters Dissertation aims contributing to the reduction of operational cost by improving warehouse operation flows, using simulation tools to study and present an alternative operations configuration of Worten's central warehouse. Therefore, the following objectives can be outlined:

Objective of the Dissertation: **Improve warehouse operation flows** – with the aid of support objectives 1, 2 and 3, propose a new micro-layout for the warehouse operations PTZ (Put-to-Zone), PTL (Put-to-

Light), Online and PTS (Put-to-Store), as well as its flows, to achieve a higher operational efficiency and lower operating cost.

Support Objective 1: **Characterize and represent an *As Is* Simulation Model** – develop a simulation model that represents the current warehouse operations and flows being studied;

Support Objective 2: **Propose a new micro-layout considering space and flows restrictions** – develop a 3D model proposal for the micro-layout of the warehouse operation zones being studied;

Support Objective 3: **Characterize and represent a *To Be* Simulation Model** – develop a simulation model to represent the warehouse operations and flows being studied, according to the new micro-layout idealized in the previous step.

1.3 – Dissertation Structure

The structure adopted in this Dissertation is presented in Figure 1.

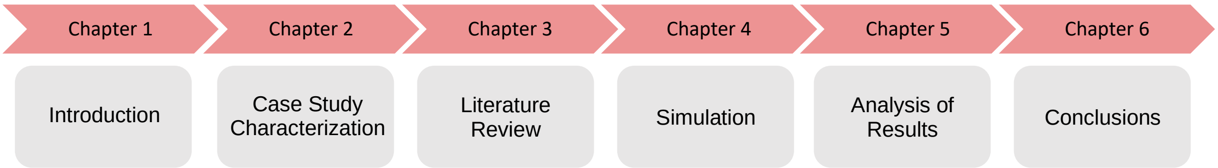


Figure 1 - Dissertation Structure

After an introduction where the problem background is detailed along with the objectives and structure of the project (chapter 1), it is characterized the case study at hand (chapter 2), with the causes that led to the problem being explained and a contextualization of the warehouse operations and flows detailed. Afterwards, it is proceeded to a Literature Review (chapter 3), where similar case studies and contexts were studied in order to obtain insights on how to approach them. Then, with the insights from the Literature Review, it is presented the methodology to approach the problem at hand. Simulation models are accurately explained as well as the new micro-layout proposal (chapter 4). Finally, the results proposed to achieve are presented and analysed (chapter 5) before describing the conclusions of the work developed and the future steps to be taken in order to give continuity to the project (chapter 6).

This work was developed through an internship at Worten in a partnership with the company, inside the Flows Engineering department. The data presented along this work was provided by Worten that allowed access to internal documentation. All the knowledge and description of concepts, decisions and fields of action required for the development of this work were acquired through constant interaction in daily activities of the company managers as well as face-to-face informal meetings with people from various departments, such as IOW (Improving Our Work), BI (Business Intelligence), Transport and Operations departments. Additionally, constant visits to the operations in the warehouse took place accompanied with the managers from each operation team in order to acquire full knowledge and understanding of the processes, flows and ways of working of the warehouse natural daily functioning.

Chapter 2 – Case Study

In this section, it is presented the case study at hand as well as the causes that led to the problem arise and the guide paths that have been drawn in pursuance of the solutions inherent to it. Firstly, a brief introduction and description of the company will be contemplated. Posteriorly, the industry in which Sonae in general and Worten in particular are inserted in will be characterized so as to precise the outcomes that will conceive the problem, which is formulated at last.

2.1 – Sonae

Sonae is a multinational Portuguese company founded by the banker and businessman Afonso Pinto de Magalhães back in 1959 in Maia, Portugal. Starting as a small and medium-sized enterprise on its early years, group Sonae had its origin in Sociedade Nacional de Estratificados which was merged in its unique field of action at the time the production of wood-based panels. During the 80s, Sonae began its expansion and in 1985 it was created Sonae Investimentos SGPS (Social Participation Management Society) which entered the Lisbon Stock Exchange. The company would then evolve through the course of the years to a group that nowadays covers many diverse areas such as modern distribution, specialized retail, telecommunications, tourism, media, insurance, new technologies, among others (*Público, March 2015)*.

In the current frame, Sonae manages a broad business portfolio - in the areas of retailing, financial services, technologies, shopping centers and telecommunications – having them in an organizational structure separated by the different business areas as subholdings: Sonae MC is responsible for the food retail, health and well-being, Sonae S&F for the specialized retail in sports and fashion, Worten for the electronics retail, Sonae RP for optimizing the retail patrimony, Sonae FS coordinates the financial services, Sonae IM works on investments management, Sonae Sierra is an international subholding dedicated to serve the necessities of investors in real estate retail and finally NOS, a Portuguese telecommunication and entertainment company in which Sonae group holds 25% of joint control, through Sonaecom. This work is focused in Worten's business area, which is detailed in the next section.

2.2 – Worten

In between this constant exploitation of new markets and fields of action, R&D developments and emergence of new brands, Worten was created in 1986 with headquarters in Matosinhos, Portugal. Being initially part of Sonae MC, Worten became in 1998 part of the recently created Sonae SR, which included both Worten and Sonae S&F. However, in 2016, due to the high business volume of the brand, Worten became an independent enterprise held by Sonae SGPS.

Currently, Worten holds more than 180 stores in Portugal spread all over the country, both continentally and islands, out of which 35 are exclusively dedicated to the commercialization of consumer electronics goods and telecommunication services, denominated Worten Mobile stores. In 2009, Worten began its expansion beyond borders and entered the Spanish market, having today over 40 stores in the neighbour country, also both continentally and Canary Islands, assuming itself as an Iberic company.

Leader of the national market in the areas of home appliances, consumer electronics and entertainment, Worten provides a wide range of products and brands, not only suppliers´ but also exclusive brands. Always pursuing to follow the most recent technological developments of the markets, the company primes to present them to customers at first hand (Worten, 2019).

The brand has been being distinguished over the years for its omni-channel strategy, this is, the capacity of integration of the various points of sale by eliminating barriers between them, offering an unique buying experience to the customers independently of the sales channel chosen (Verhoef et al., 2015) through which Worten's points of sale are more attractive, more appealing and with a specialized attendance and service value (as it is an example the post-sales service that the company offers to its clients). The permanent focus on customer satisfaction and the pursuit of the best service level performance rewarded the company with a perceived value by the market that recognizes Worten as a confidence brand. This was materialized by the winning of "Best Portuguese Store" prize for retailer of the year 2018 in the home appliances and consumer electronics category for the Grande Consumo and Q&A consultant partnership (Grande Consumo, 2019).

2.3 – Worten Supply Chain

Worten started, as said before, for being a company specialized at home appliances´ goods and with the course of the years started exploring the technological market niche, turning itself into a consumer electronics and entertainment designed company. In the internal perspective, this required a repositioning of the brand in the market and the need to be recognized by the consumers as such, which effectively was possible as the strategic goals established were successfully accomplished.

Additionally, the consumer expectations have changed dramatically over the years. Where once the consumer´s buying experience passed mainly by the physical environment of walking into a store and search for the intended product with few or none knowledge in advance, now, privileged information is available for whoever wants to search for it, through the ease of internet access and online sales channels. The customer is regarded with well-known perception of the different values of products and geographical issues are no longer a barrier: anyone can order anything from anywhere at any time.

In order to meet the new customer´s requirements as well as to keep in line with the strategic goals of the company, Worten´s supply chain had to be re-designed with the main focus on the omni-channel strategy, which resulted in several structural changings. Initially the supply chain was linear (Figure 2), where suppliers provisioned a central warehouse, which stored the products and prepared the orders to be shipped to different retail stores throughout the country until reaching the final customer. In order to meet the most recent market demands, there was a need of creating several different flows with the creation not only of logistic hubs (centres or specific areas dedicated to deal with activities related with transportation, separation, organization and distribution of goods closer to the final customer), physical supply stores (stores dedicated not only to selling products but also to store and supply other stores) and online stores (virtual stores dedicated to e-commerce), but also with the integration of drop shipping (direct delivery of products from supplier to final customer without passing by the central warehouse) and cross docking concepts, in what became a networked supply chain (Figure 3).

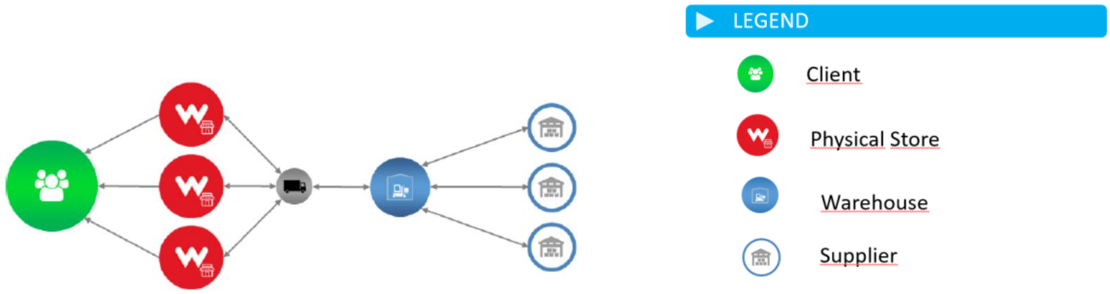


Figure 2 – Linear Supply Chain (Worten, 2019)

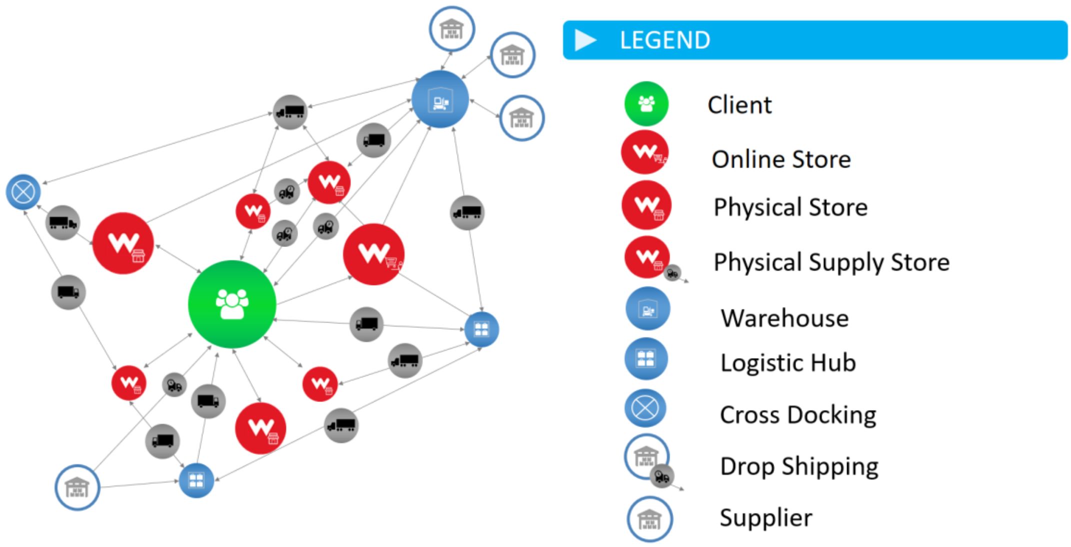


Figure 3 – Networked Supply Chain (Worten, 2019)

2.4 – Worten's Warehouse

Located in Azambuja, in the centre of Portugal, the warehouse supplies all the Worten stores in Portugal and all the flows and operations converge in this area of approximately 50.000 square meters.

The adherence in November 2016 to the Black Friday concept, in which, for 24 hours, the company practices serious price reductions, promotions and discounts, results in the highest peak of demand of the company. On the top of that, the continuous exponential growth of the online business unit and the general expansion expected for the company in the future came up with the need of fully re-designing the warehouse layout, from the storage requirements to the flows and operations inside it.

Firstly, it is mandatory to notice that Worten sells a wide range of different products with opposing characteristics in terms of dimensions, volume, value, storage, handling and holding requirements which go from refrigerators to memory cards, passing by laptops and smartphones.

Looking to the warehouse layout as it currently is, it is possible to observe from Figure 4 the main storage locations and operation flows, described as follows.

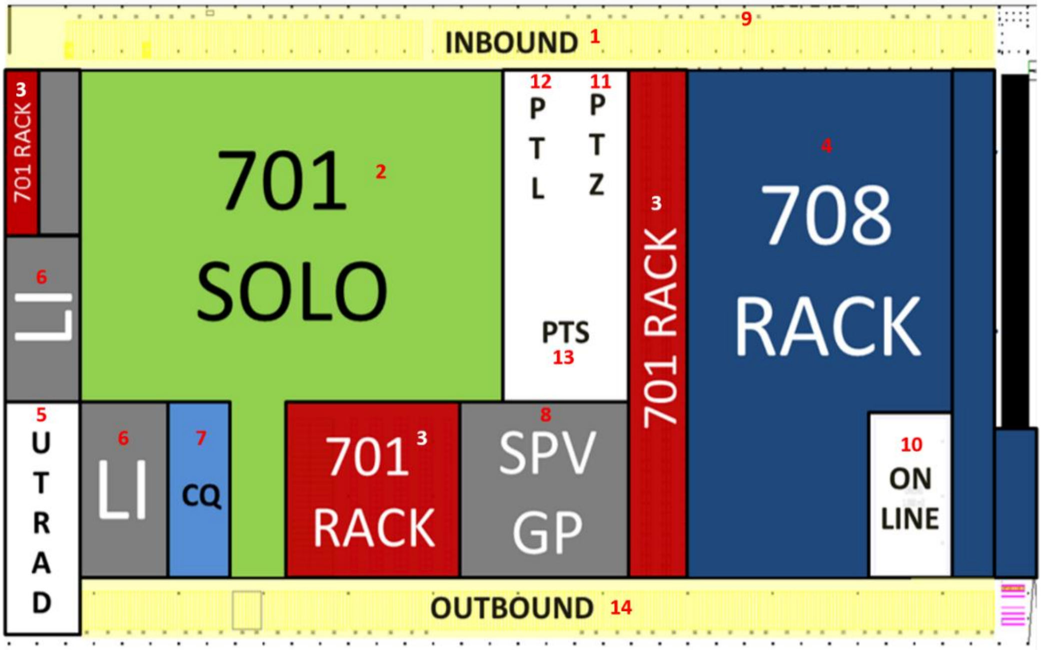


Figure 4 – Layout As Is

1. **Inbound:** trucks arrive to the outside inbound docks in one side of the warehouse and are unloaded onto an inside receiving area;
2. **701 Solo:** block stacking - big sized home appliances, such as refrigerators, stored and stacked overlapped on the floor;
3. **701 Rack:** rack storage of home appliances that require the use of racked pallets;

4. **708 Rack:** rack storage of the consumer electronics and entertainment through the use of boxes or pallets. Inside this area, there is also a drive-in storage system dedicated to low sized home appliances stored with resort to pallets;
5. **UTRAD:** repairment of damaged products for further outlet selling;
6. **LI:** Reverse Logistics – product storage and refurbishment for further replacement;
7. **CQ:** product quality control;
8. **SPV:** Post-Sales service;
9. **LAV:** mezzanine storage, located above the inbound docks, of high value products such as laptops or smartphones for stricter control;
10. **Online**: area designated for all the operations related with the online service of the company;
11. **PTZ** (*Put to Zone*): product sorting by corresponding PTL sector preparation zone;
12. **PTL** (*Put to Light*): product sorting by store;
13. **PTS** (*Put to Store*): where all the different orders´ fulfilment flows of consumer electronics products converge in a fixed and specific store location;
14. **Outbound:** trucks arrive to the outbound docks (located on the opposite side of the warehouse in relation to the inbound docks) and there products are loaded.

2.4.1 – Main warehouse flows

The main warehouse flows can be divided in two, reception and expedition flows, which are then subdivided in different categories, as structured in Figure 5.

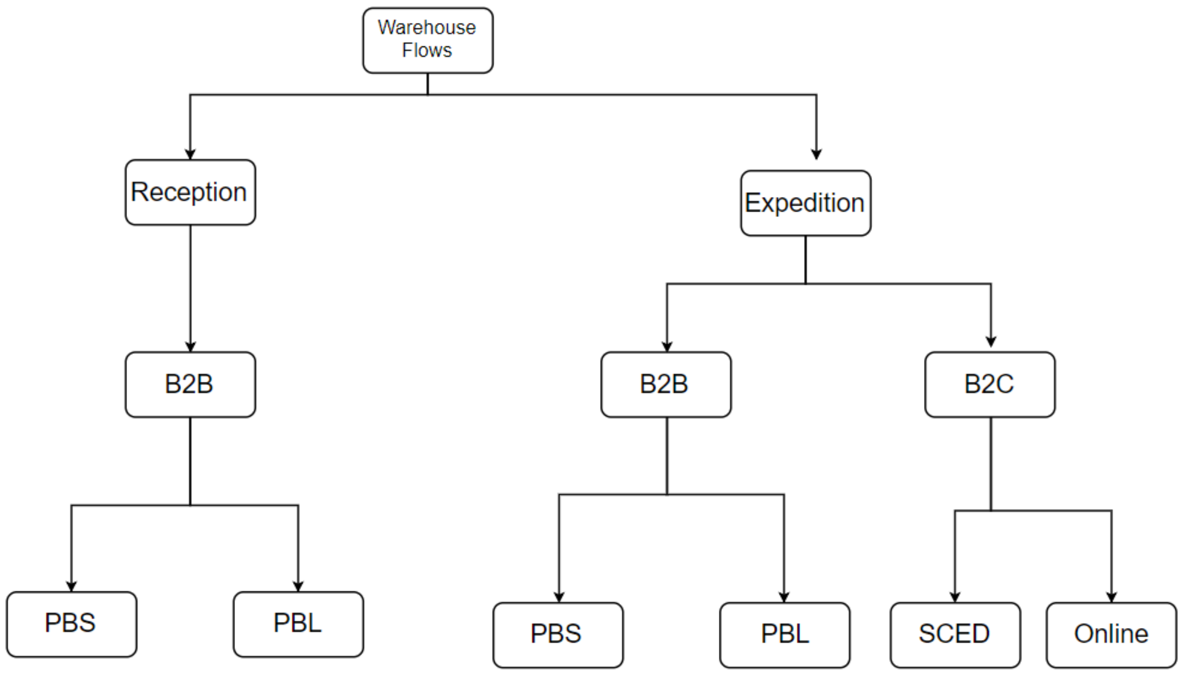


Figure 5 - Warehouse Flows

For a better understanding of this chapter and ease of reading, they were developed flow diagrams, which are presented in the Appendix section. Using the Google tool draw.io, the purpose of the diagrams is to serve as a visual auxiliary tool for a better consolidation of information collected in the visits to the operations.

In what concerns reception flows, there is no distinction between B2B *(Business to Business)* or B2C *(Business to Consumer).* The reception flows are, then, always considered as B2B, which is then divided in two subsequent separate flows: PBL and PBS.

The PBS (Pick by Store) flow is characterized by the need of storing products prior to shipping. At the time products are received at the warehouse, they are stored. This need is related with products whose suppliers have low service levels in terms of both irregularities in the accomplishment of delivery dates and quantities or with suppliers whose delivery times are long (for example, merchandize imported from intercontinental countries that travels through containers by sea-based transportation). Being the most traditional warehouse flow it is, however, less productive and more expensive due to the need of retaining inventory and stopped product at the warehouse. When an order is placed for these products, batch picking is done: an operator, with the aid of an electric pallet truck, transports two empty pallets, each of them corresponding to a Worten store, and fills them with the products picked from storage. These pallets are then sent to the PTS area before proceeding to the outbound docks if no quality control is requested (see Appendix 1).

The PBL (Pick by Line) flow, contrarily, does not require to have inventory at hand and is similar to a cross-docking operation - products are shipped at the same day they are received. Products are sorted by preparation zone at the act of reception and expedited at the end of the day. This flow is related with high service level suppliers that have various delivery windows during a week avoiding retaining inventory. There are, however, certain exceptions as it is the case of a supplier that delivers on day *x* and *x+2*, and the product is intended to leave for a certain store on day *x+1*. In this specific case, this product might be stored until day *x+1* (See Appendix 2)*.* In these cases, products are bulk picked – one operator, with the aid of a forklift, picks all the products that all the stores ordered for that day. Afterwards, these products will be sorted by their corresponding preparation zones.

Products that leave the warehouse may have different recipients which include Worten stores (B2B) - PBS and PBL flows - or final customer (B2C) in the form of home deliveries of orders placed online and big-sized home appliances (SCED). Depending on the recipient, and on the type of product being sold, Worten contracts three different transportation companies – internal operator (IO), express operator (EO) and SCED ("Serviço Complementar de Entregas ao Domicílio" - Complementary Service of Home Deliveries) operator. The internal operator accounts for the pre-established routes and delivery windows from the warehouse to the stores flows (mainly PBL and PBS flows); the external operator has an everyday route for home deliveries (mainly online order flows) and finally SCED operator also works for home deliveries but of big-sized home appliances, which have a service provision associated for the instalment of goods.

The products from all these flows (PBS, PBL, Online & SCED) are prepared, wrapped if necessary in a wrapping zone close to the outbound docks and finally, are put in the corresponding outbound dock. Each outbound dock will have an assigned truck which will be loaded and deliver the products according to an established route.

Prior to the loading, the expedition team commonly checks if it is possible to consolidate merchandize. This is, if there are two pallets to be delivered in the same destination, it is analysed the possibility of aggregating the products of both pallets in just one pallet, so as to reduce transportation costs (once Worten is charged on a transportation rate per pallet).

From the total of units shipped for the B2B flow, roughly 50% of them are from PBL flow and 50% from PBS flow. This split will have an important impact on the development of this work, namely related with the intent of preparing orders from both flows in the same manner in order to reduce operating costs.

The Online flow will be explained in detail with the operations associated with this area. SCED flow will not be studied in detail once it is out of the field of study of the present work.

2.4.2 – Main warehouse operations

For the purpose of the present Dissertation, warehouse operations will be mainly focused on central zone – Put-to-Zone (PTZ), Put-to-Light (PTL), Online (ONL) and Put-to-Store (PTS). These areas will be grouped in the centre of the warehouse, with the dimensions/capacity of each suffering considerable adjustments, when considering as starting point the current layout (*as is*). In Figure 6 it is possible to have a broad view of the inputs and outputs of each of these zones as well as the interaction of flows between them (blue arrows represent inputs and red arrows represent outputs).

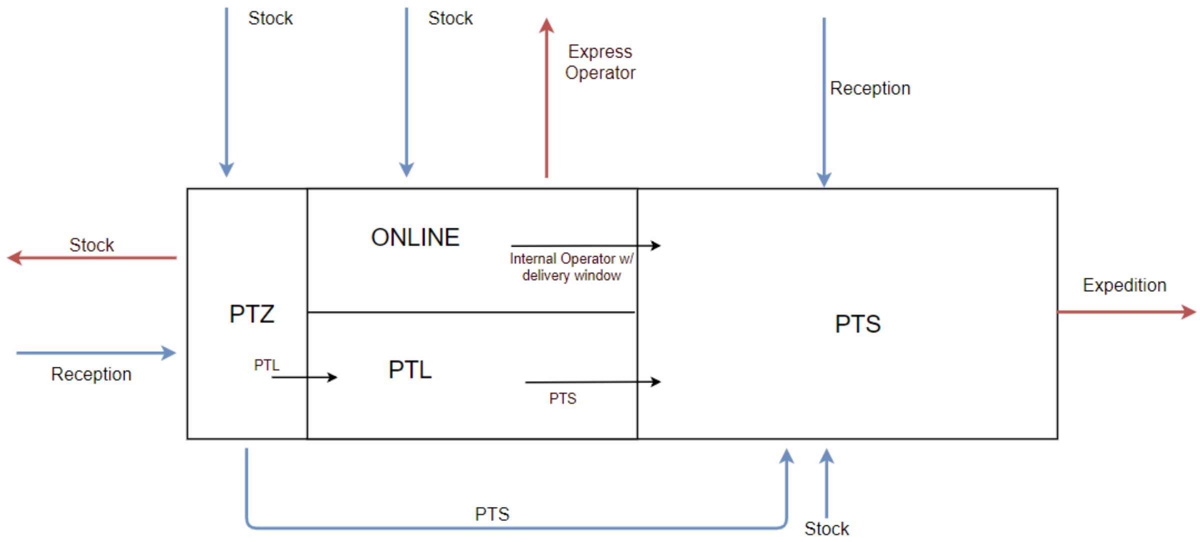


Figure 6 - Main Warehouse Operations

As said before, products that arrive at the warehouse may be from PBS or PBL flows. Out of the three main types of products Worten sells - home appliances, consumer electronics and entertainment - the home appliances goods, which generally arrive as single units without resort to pallets or any other support base, always correspond to the PBS flow, once these products have long delivery times and there is the need of holding stock at the warehouse so as to better respond to orders. In reference of the other types of products, they arrive in pallets and at the time of reception it is checked the type of flow associated with each specific pallet – PBS or PBL.

In the case of PBL flow, these pallets may be single-SKU or multi-SKU, which corresponds to pallets with a single type of product or with multiple types of products, respectively. When the operator scans the Inbound License Plate Number (ILPN) of the pallet, the system will indicate one of each of the three following types:

Fully allocated: all the products in the pallet are to be expedited in the same day they were received, once they already have a distribution order associated – the pallet is taken to the PTZ operations area;

Partially allocated: contains products that can be either for stock (if that order does not have delivery date in that day) or for expedition – the pallet is taken to the PTZ operations area;

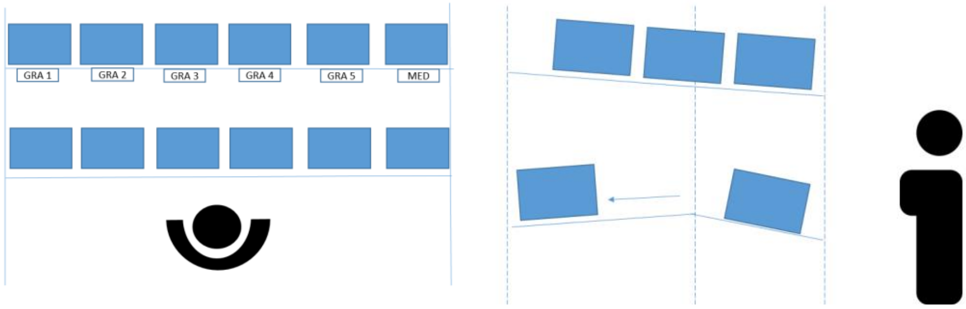
Put-away: all the products in the pallet are to be stocked in the respective location of the warehouse storage area, once that order does not have delivery date in that day – the pallet awaits an operator to pick it and store the products.

In the case of PBS flow, all the pallets are stored in its respective locations. In the next sections, each operation will be explained in more detail.

2.4.2.1 - PTZ – Put-to-Zone

This operation (see Appendix 2) receives as inputs pallets from both reception and stock. From reception, the pallets might be fully or partially allocated. From stock, pallets are always fully allocated once products were picked to satisfy specific orders placed for that day from different stores. In the case of fully allocated pallets, the products might proceed to the PTL or PTS zones, depending on the size of the product – if the product´s volume is less than 6L (six liters) it proceeds to the PTL operations area otherwise, the operator takes it by hand directly to PTS. In the case of partially allocated pallets, the products that have an order associated follow the same procedure of the fully allocated and the *left-overs* are stored in a near zone to be stocked afterwards (Stock).

Inside the PTZ operation, the procedure of sorting by PTL destination sector, there is a rack with two different levels at different heights each of them with totes stored. The lowest level has 6 totes, each of them corresponding to a different destination in the PTL operation zone - GRA1, GRA2, GRA3, GRA4, GRA5 and MED. The top level has empty totes to replenish the lower level ones when these are sent to its corresponding PTL destinations (se Figure 7).



(a) (b)

Figure 7 - PTZ front view (a) & side view (b)

When a pallet arrives, the operator scans the European Article Number (EAN) of each SKU and the system will inform the quantity of that SKU that is allocated to which PTL sector. Once a certain tote is full, the operator pushes it (blue arrow in the Side View in Figure 7) and another operator is responsible for picking that full tote from the opposite side of the rack and transport it to the corresponding PTL sector.

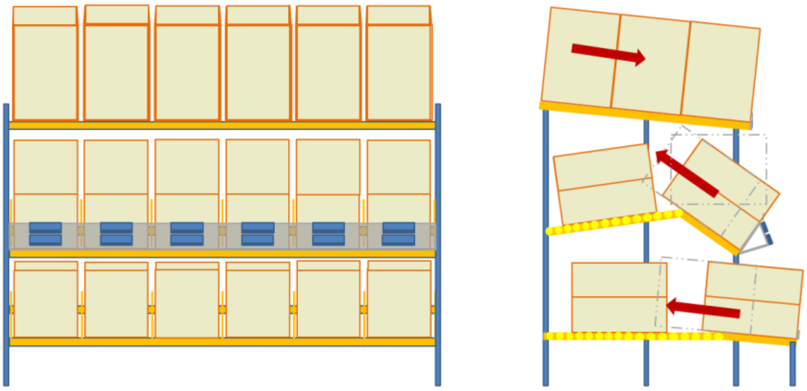
2.4.2.2 - PTL – Put-to-light

This section is divided in 3 different categories depending on the system type of the products – GRA (“GRAnde”, *big*), MED (“MEDio”, *medium*) and PEQ (“PEQueno”, *small*) – which correspond to 7 different sectors (category GRA is subdivided in five different sectors – GRA1, GRA2, GRA3, GRA4 and GRA 5). The 3 categories have various boxes with each of them corresponding to a specific Worten store (in PEQ and MED there are all the 180 stores and in GRA, these 180 are divided in the five sectors, with 36 stores in each sector, once the boxes in these sectors are larger).

In the PEQ sector, products come directly from reception without passing by the PTZ operation´s area, that is why this is the sector located closest to the receiving docks. This is due to the low size of the products, to which a simple table is sufficient to unpack them and directly sort by destination store.

The MED sector works in a similar manner to the PEQ, however the input are totes coming from the PTZ operations area and already explained in the previous section.

Each of the GRA sectors has three racks, displayed in a U shape, with each of them containing three levels (see Figure 8). The top level contains empty boxes to replenish the lower levels when full boxes are sent to PTS. The middle and low levels correspond to Worten stores.



(a) (b)

Figure 8 - PTL front view (a) & side view (b)

In each of the sectors, an operator scans the code of a certain item. The system will turn on lights that have a box assigned corresponding to a specific Worten store and indicate the quantity of units of that product that is intended to be put in that box/store. The operator places the items accordingly and proceeds until the tote is empty. When a box is full, the operator pushes it and another operator is responsible for picking that full box from the opposite side of the rack and transport it to the PTS reception zone (red arrows pointing from right to left in the "Side view" in Figure 8).

2.4.2.3 - PTS – Put-to-Store

In this consolidation operations area, there are pallets spread on the floor through four corridors with each corresponding to a specific Worten store. Products are placed in each store throughout the day and, at the end of the day, the pallets of the stores with delivery window in that day, are collected and sent to expedition. The products might come from different flows: from the PTL sector as closed boxes, from the Online sector if they are intended to be delivered in stores with delivery window in that day ("Internal Operator with delivery window"), directly from reception (in the case it is, for example, a pallet fully allocated containing only large products above 6 liters in volume), directly from PTZ and from Stock.

2.4.2.4 – Online

Once the Online operation accounts for both a warehouse operation and an expedition flow, it will be described considering these two concepts. The online operation works in very particular way due to the short delivery time window that Worten proposes to accomplish to its clients: the company assures that the order arrives to the customer 24 working hours after the placement in the online platform. The customer has two options of receiving the product(s) ordered: at home (home delivery - HD) or in a Worten Store (pick up in store – PIS). In this section, the products can only be of two types – short or large – such as the orders – mono or multi. A mono order is one that contains only one item whereas multi orders have more than one. Multi orders might also be only of short products, only large products or a combination of both.

This area is then divided in different parts (see Appendix 3): products arrive from picking to a receiving area and depending on the type of product – large or small – the operator moves them to the assigned part. Typically, small products are picked into totes whereas large products are picked into pallets. If the product is small, the operator scans the product and checks if it is a mono or multi order. If it is multi, the product is placed in a honeycomb shelving, denominated Putwall (PTW) close to the receiving area and will remain there until the other products from that multi order arrive. If the product is from a mono order, it is taken to a Packing Station where an operator will pack, wrap, check payment status, print invoice if necessary and place it in a conveyor that will transport it to a sorting zone. The same happens to multi orders of small products when they all have arrived. If the product is large, it is taken to the designated large tables where the operator does the paper work, wraps the product if necessary and takes it by hand to the sorting zone. The same happens to multi orders of large products when they all have arrived. In the case of a mixed multi order, for example a printer and a toner, the products are aggregated in the large tables zone and taken by hand to the sorting zone.

Regarding the sorting zone of the online section, it is divided in two parts. The small products that arrive to a buffer from the conveyor are sorted to 4 different zones each of them with a Put-to-Light system similar to the one described above. The products are then sorted to a specific box corresponding to a certain destination, being it a store or home delivery (all these destinations are divided into the four PTL zones). Close to this put to light system, there are pallets on the floor also corresponding to stores where some of them are to be delivered by internal operator (IO) and others by express operator (EO). If the products are to be home delivered or to be picked up in a store that does not have delivery window in that day, they will be transported by EO, otherwise, they will be taken to the PTS zone of the warehouse to be expedited and posteriorly, delivered by the IO.

2.5 – Problem Definition

Nowadays, the retail industry has growing pressure to reduce operating costs and improve productivity. Specifically, in Supply Chain Management, this demand is imperative for any decision within the system. Worten board identified various challenges to its Iberic supply chain in order to meet the market trends of the industry.

The market has become more demanding in terms of lead times. In the online business, the customer wants the product as soon as possible and if there is a competitor that delivers the same product in a shorter period of time, that is the one that will be typically chosen. There is then the necessity of acting on the limits of the capacity and Worten proposes to deliver the products to the client in the next business day after the order is placed online. Also, deliveries on the same day and even in 2 hours after the placement of the order are also targeted by the company, with resort to logistic hubs: through a correct provision of products in these hubs, it is possible to achieve this intent once the products are closer to the client and less time they take to reach their final destination.

In regard of the omnichannel strategy defined by Worten, there is the objective of expanding it in two different axes: deepness and width. There is the desire of achieving the best possible balance between quantity and variety of the products offered to the market. This will have a considerable impact on warehouse operations on behalf of the difference between storing and sorting more quantities of the same product or smaller quantities of different products.

Additionally, the growing business in Spain forces the company to safeguard the correct inventory level and an accurate stock assignment to meet the demand, which also has considerable effect on space, storage and operations management of the central warehouse, once part of the products sold in Spain, such as the own-labelled, are supplied by this warehouse.

Finally, there is the need of satisfying Worten´s marketplace clients´ demands by assuring the correct functioning of logistics services. This requires a skilful integration of warehouse operations and space.

Having clearly outlined these objectives, the company felt the need of fully re-design the warehouse layout and adapt its operations to the identified trends. The added value of the logistics processes of the warehouse is represented in the warehousing, storage and operating efficiencies, with the support areas being the movements efficiency and the operational aid. Keeping this in mind, a new warehouse layout was proposed by the Flows Engineering department and posteriorly approved by the board of directors of the company (Figure 9). As said before, the present work is mainly focused on the areas PTZ, PTL, ONLINE and PTS.

The Online business unit of the company has grown exponentially, at a rate of approximately 50% per year, in the past years. At the time the Online business unit was created, it was located at one corner of the warehouse – see Figure 4 – because there was only space available in that area and it still represented a very short part of the Worten's business in terms of income. Now, the Online distribution channel is growing exponentially, also due to the new tendencies of the market. Therefore, there are lots of inefficiencies associated with the localization of this operations area, both in terms of distances to travel from storage locations and time consumed in the operation. With this, it was concluded that the Online area would have to be moved to the centre of the warehouse and close to the other operations that connect the inbound and outbound flows so as to minimize those inefficiencies.

Additionally, there was the intent of storing high rotation products closer to this central area, with the same idea of reducing picking distances and times. However, this relocation of products would lose its effect if the Online operation´s area kept where it was, since it is one of the main demand operations for high rotation products. It was then decided that Online would move to the central area, located on the right side and the PTL on the left side because the PTL inputs come from PTZ and Online inputs come from storage locations (708) – see Figure 9.

With the Online occupying the previous PTZ zone, it was necessary to reallocate PTZ. Once the inputs of this zone are reception and stock, it was located the closest to the inbound docks.

For a similar reason, PTS was located the closest to the outbound docks – the only output is expedition.

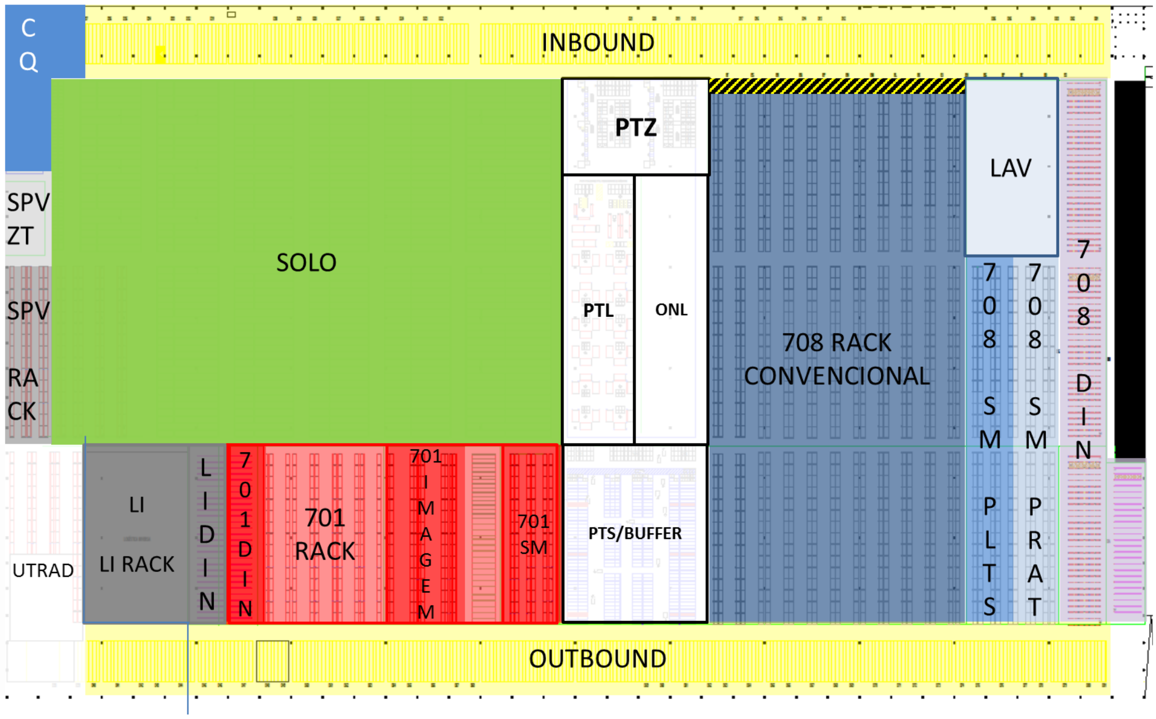


Figure 9 - Layout To Be

2.6 – Worten's Warehouse Layout Redesign – Project Phases

The work to be developed in this Dissertation is part of Worten's project to redesign the whole layout of the warehouse. This umbrella project was defined by company managers in 6 steps:

1. *Requirements Understanding*: characterize the business necessities;
2. *Analytics Understanding*: transpose the necessities to logistics requirements;
3. *Layout Preparation*: definition of the new layout proposal;
4. *Analysis and Modelling*: simulation of the different scenarios with basis on benchmarks and evaluating the response to the requirements, taking into account the logistics´ operations efficiency and the return on investment (ROI);
5. *Validation*: operational and financial validation of the final proposal;
6. *Implementation*.

At the time the internship supporting the Dissertation at the company started, due to the four main drivers identified in section 2.5 (Step 1) and in order to improve capacity and efficiency at a lower cost (Step 2), the board had already approved the warehouse macro-layout proposal (Step 3), with the result presented in Figure 9. With this being said, steps 1, 2 and 3 were already concluded. The project was therefore, at that time, addressing Step 4 - simulation and study of different scenarios. With various layout changes taking place in the whole warehouse, the work assigned to this Dissertation focuses on the central warehouse zone – PTZ, PTL, PTS and Online. With the new locations clearly outlined and measured, the purpose of this work is to draw the best process inside each of these four zones as well as the flows between them and its micro-layouts always pursuing to improve capacity and productivity at a lower cost from what is done today. For that, a simulation model had to be developed to assess the required outputs of that central zone with the purpose of comparing the results of the proposed solution (*to be* scenario) with the current one (*as is* scenario) which constitutes the operational validation. Afterwards, contacts with different suppliers will take place in order to obtain a financial budget for the project, which will constitute the financial validation. Finally, it will be done a cost-benefit analysis, comparing operational and financial validation (Step 5) which will lead to the implementation of the proposal (Step 6).

However, once the new warehouse layout has already been approved, the four mentioned zones will be moved to their new locations with their current operating policy before the implementation of the new proposed operational solution, this is, when the implementation of the operational solution takes place, these zones will already be located in its final destinations with a temporary layout. Once the warehouse cannot stop working for the implementation of the new layout, this movement of working zones must be staged according to the following logic: firstly, the PTS area will be pushed close to the outbound docks, secondly PTL will take its final location, followed by PTZ and finally Online will be brought from the corner of the warehouse to its new central location. This sequencing is related with the remaining operations of the warehouse and was defined to minimize the overall operating impact of the warehouse natural functioning.

Chapter 3 – Literature Review

After the presentation of the case study in the previous chapter a literature review on the related concepts with the problem at hand will be made. The objectives of this chapter are to define important concepts related with this work and present a methodology with basis in literature reviews to serve as a reference to the problem at hand as well as suitable tools used in similar works.

Being warehouse management and layout design the central basis of this work, this chapter is divided in two distinct parts: in a first phase, it is started by the whole – general concepts related with retailing, supply chain management and logistics - until reaching the specific – warehousing. In a second phase, a more specific literature study is done in terms of methodologies and approaches to similar problems as well as a conclusion on the useful tools and methods that shall be taken into account in the further development of this work.

Section 3.1 starts with a conceptual literature review and study of different definitions of work-relevant concepts. Gradually, it is presented how these concepts and its applications have changed during the course of the years until reaching the today´s perceptions (Section 3.1.1). Afterwards it is explained in Section 3.1.2 the relevance of running warehouses in a Supply Chain as well as its benefits and associated trade-offs. Posteriorly, the challenges of a warehouse manager (Section 3.1.3) are presented followed by the different factors, methodologies and approaches to take into account when designing a warehouse layout and its operations (Section 3.1.4). Finally, the transition between traditional and modern warehouses is exemplified with the emergence of the cross-docking operation (Section 3.1.5) ending with the presentation of current warehouse trends and the future vision of warehousing-related activities (Section 3.1.6).

In Section 3.2, a scientific research is done. Firstly, the most common Key Performance Indicators (KPIs) of warehouses are presented in order to accurately evaluate results of a warehouse layout and operations design approach and its impact in the supply chain performance (Section 3.2.1). Secondly, they are proposed tools and techniques, in a general framework of steps, for specific areas of analysis (Section 3.2.2).

In Section 3.3, general concepts related with simulation tools and techniques are presented (Section 3.3.1) and afterwards it is explained the importance of simulation and modelling in these types of problems as well as its relevance for the purpose of this work (Section 3.3.2).

3.1 – General concepts and their evolution

3.1.1 – Retailing, Logistics & Supply Chain

Retailing is part of our everyday lives. Retailers fulfil the economic role of making products and services available to consumers and we rely on them to supply our needs (Gupta & Randhawa, 2008).

According to Kotler & Armstrong (2008), retailing relates to all the activities that are involved in the selling of products and/or services directly to the final consumers for personal, nonbusiness use. Zentes et al. (2007) go further and define retail companies as the ones that are primarily involved in the activity of purchasing products from other organisations with the intent of reselling them to a final costumer without the need of transforming them.

However, the concept of retailing has suffered considerable changings due to the development of markets and consumer behaviour. Traditionally, a retailer was considered a passive distributor, which was nowadays transformed into an active intermediary that controls the product range offering, carefully selecting products from manufacturers and making them available to consumers (Varley, 2014). The technological advances and the high speed of development of new systems for supporting both retailers and consumers inherent to it (Gunday et al., 2014) have subjected the retail industry to constant changing and adaption to the new trends. The enormous availability of advanced technologies that might be introduced in the different points of sale as well as the consumer´s interests in new systems that can support and enhance the shopping experience (Chiu et al., 2010; Oh et al., 2012) forced retailers to innovate and clearly understand what consumers need so as to keep or increase the business profitability (Pantano & Viassone, 2013).

The relationship between retailing and logistics is highly concerned with the product availability, quantified as getting the right products, in the correct place at the proper time (Fernie & Sparks, 2009). According to Christopher (2016), logistics is defined as the process of strategically managing the procurement, movement and storage of materials, parts and/or finished inventory as well as its respective related information flows, through an organization and its marketing channels with the aim of maximizing the current and future profitability by reducing operating costs through cost-effective fulfilment of orders. It is a planning orientation and framework which seeks to create a plan for the flow of both products and information through a specific business. Nonetheless, it is imperative to differentiate the concept of logistics from supply chain. Although directly correlated one with another, supply chain accounts for a wider concept than logistics and is defined as the integration of key business processes from an end user through original suppliers that provides information, services and products that create an added value not only for customers but also for stakeholders (Lambert & Cooper, 2000). The Council of Supply Chain Management Professionals (CSCMP), recognized as the official entity of professional experts in this field of study, describe supply chain management as the active management of all the supply chain activities, which include product development, sourcing and production to logistics, as well as the information systems needed to coordinate these activities, in order to maximize customer value and achieve sustainable competitive advantage (https://cscmp.org, consulted in May

2019). Logistics is, then, a subset of the supply chain that serves as a link between manufacturing and selling processes that culminates in the creation of place and time utility (Ismail, 2008).

3.1.2 – Warehousing

Warehousing has become a core competency, a strategic weapon that companies are using to reinforce their competitive position (Tompkins & Smith, 2008). A warehouse is generally defined as a temporary place to store inventory and as a buffer in supply chains. It works as a static unit that aims to better match product availability to consumer demand, facilitating the movement of goods from suppliers to customers by meeting the demand in an accurate, timely and cost-effective manner (Van der Berg, 2011). A warehouse should then be seen as a transhipment point where goods received are despatched in a quick, effective and efficient way (Richards, 2018). Gu et al. (2007) add that warehouse management is an integrating part of the supply chain that plays an important role regarding the effective delivery of goods to clients.

Apart from buffering the material flow along the supply chain to accommodate variability caused by factors such as product seasonality or batching in both production and transportation (Gu et al., 2006), Bartholdi and Hackman (2016) concluded that storing inventory in intermediate points reduces the overall supply chain costs by minimizing the transportation costs which would be higher in the case of direct delivery from production to end consumer points as it is shown in Figure 10.

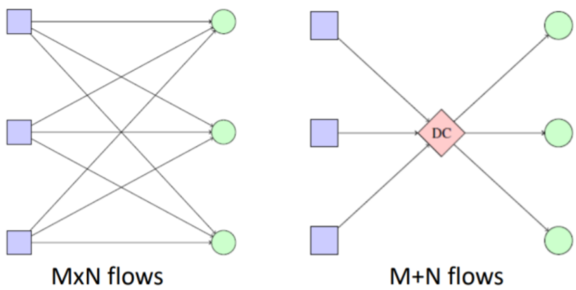


Figure 10 - Diagram of a simple Supply Chain with and without warehouse (Bartholdi & Hackman, 2016)

Additionally, warehouses allow the consolidation of products from various suppliers for combined delivery to customers as well as value added processing by specialized operations carried out such as pricing, labelling, customization or kitting (Gu et al., 2006).

Despite all the advantages mentioned above, warehouses end up being costly: land capital, storage and handling equipment investments, maintenance, labour and information systems are some of the costs associated with running a warehouse. It is required to evaluate the trade-offs, weighting advantages and disadvantages that Richards (2018) identified as:

- Cost vs service;
- Storage capacity vs speed of put-away and retrieval;
- Speed vs accuracy;
- Lower inventory vs stock availability;
- Efficiency vs responsiveness;
- Volume purchases vs storage cost and availability;
- Transportation costs vs storage costs.

3.1.3 - Warehouse Management

Warehouse management is based in two main pillars: space and time (Richards, 2018). In the recent years, the *modus operandi* of warehouses has been undergoing considerable changes that make warehouse excellence hard to achieve. These challenges include the following:

- Increased customer service requirements;
- Demands to reduce inventory;
- Need for increased integration of the warehouse within the total logistics system;
- Increased demands for responsiveness to address Quick Response, Cross-docking, Just-In-Time and Efficient Consumer Response efforts;
- A significantly larger number of stock keeping units (SKUs);
- Need to serve a growing variety of customers;
- Recent trends for inserting automation;
- Demands to increase warehouse operating efficiency and space utilization.

From all the challenges pointed out above, the last one is extremely relevant once it is the purpose of the present Masters Dissertation. The growing competition in the retail market forced companies to continuously improve its processes design in its distribution networks (Gu et al., 2010). Mishra et al. (2011) express that an efficient warehouse management contributes drastically for inventory costs minimization as well as reducing lead times. This largely relies on warehouse processes optimization and layout design. It is then imperative to understand the different warehouse operations and how to measure and quantify warehouse productivity.

3.1.4 - Warehouse Design Layout and Operations

A good warehouse layout is one that increases output, improves product flow, reduces costs, improves services to customers and provides better labour conditions. When designing a warehouse layout, Park & Webster (1989) defend that the functions are given and from this starting point, equipment types, storage rules and order picking policies are selected in order to minimize costs. Gray et al. (1992) have a similar approach to this theme. They propose a multi-stage hierarchical approach, which uses simple calculations to evaluate trade-offs and prune the design space to a few superior alternatives. With the use of simulation softwares, resulting alternatives are evaluated. Finally, Yoon and Sharp (1996) aimed for the exploitation of the design space in terms of order picking systems, which include different stages such as design information collection, design alternative development and performance evaluation. Anyhow, in the specific case of this present work, the definition of the departments is already given with the goal being on how these departments will interact in the most suitable, efficient and cost-effective way (Meller & Gau, 1996).

Tompkins & Smith (2008) defined the functions performed in a warehouse as receive, store, pick and ship. Traditionally, warehouses receive Stock Keeping Units (SKUs) from suppliers and store them. When orders from customers are received, SKUs are picked and assembled for shipment (Gu et al., 2007). The adoption of new management philosophies such as Just-In-Time (JIT) or lean production brings new challenges in terms of warehouse systems – tighter inventory control, shorter response times and greater product variety – but also new opportunities to improve warehouse operations with technological developments in the area – information technologies (IT), radio frequency communications (RF), warehouse management systems (WMS) (Gu et al., 2007).

3.1.5 - Cross-docking

One concept that follows this approach of exploiting new trends and opportunities taking advantage of technological advances and that is related with the purpose of the present work in terms of the PBL flow, is cross docking. Van Belle et al. (2012) define cross-docking as the transfer of incoming shipments directly to outgoing vehicles without storing them in between. Kinnear (1997) assumes that cross-docking is the act of receiving a product from a supplier for different end destinations and consolidate this product with other suppliers´ products for the same final delivery destination. The advantages of cross-docking include cost reduction, shorter delivery time, improved customer service, reduction of storage space and faster inventory turnover.

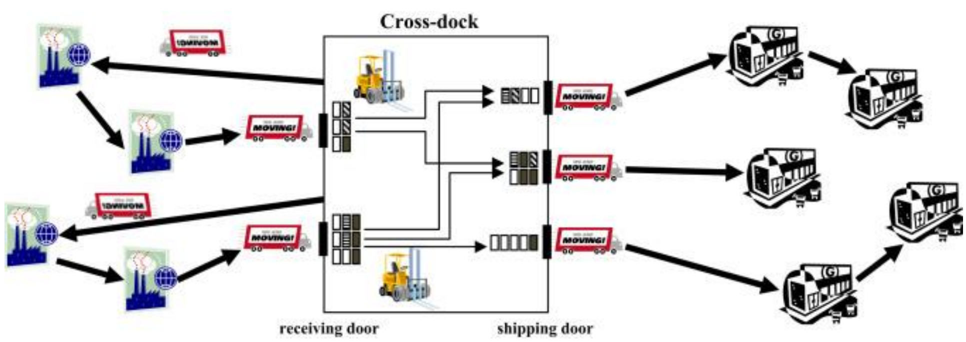


Figure 11 - Cross docking operation

For this system to work properly it is, however, necessary that all stakeholders are coordinated (CSCMP, 2013). Once there is no storage buffer inside a cross-dock, local and network-wide cross docking operations have to be carefully synchronized (Buijs et al., 2014). In this sense, there is a high degree of information that needs to be meticulously shared between the partners. In Table 1, different problem classes and decisions involved in a cross-docking facility are presented.

Table 1 – Decision Problems related to cross-docking (adapted from Buijs et al., 2014).

Problem Class	Individual Decisions Problems
Network design	Network structure and facility types Number of cross-docks Location of cross-docks
Cross-dock design	Shape of the cross-dock Number of dock doors Capacity & Design of staging area Automation of material handling equipment
Network planning	Capacity planning for network routes Freight flow allocation Shipment to destination assignment
Network scheduling	Shipment dispatching Collection and delivery vehicle routing
Cross-dock planning	Dock door specification Strip door assignment Stack door assignment Equipment and workforce capacity planning
Cross-dock scheduling	Offline/Online scheduling of inbound trailers Offline/Online scheduling of inbound trailers Internal cross-dock workforce scheduling Staging area utilization/shipment allocation Shipment to outbound trailer assignment

3.1.6 – Trends in Warehouse Management

As said before, supply chains are becoming more integrated, with globalized operations, where customers are more demanding and technologies changes occur rapidly (Ramaa et al., 2012). This sub-chapter aims to study what have been the developments in the course of the years in warehouse management, design and operations definition and steps taken towards innovation in the light of the current literature.

According to Ramaa et al. (2012), a Warehouse Management System (WMS) is a database driven software that has the aim of improving warehouse efficiency by directing cutaways and maintaining accurate inventory control by recording warehouse transactions. An advanced and well-coordinated WMS opens new opportunities to be explored, such as automation.

Especially in Western Europe and North America, in the past years, steps towards automated warehouses have been taken triggered by a high pressure to decrease the operational costs. Traditionally, warehouse operations such as order picking, transportation and materials handling are done by humans, which account for more than half of a warehouse´s operational cost costs (Hamberg & Verriet, 2012). Furthermore, there is scarcity of suitable warehouse space and more and more qualified staff is difficult to attract, which justifies this new trend to answer to the cost and unavailability of human operators.

Automation comprises the independent operation of a technical system in line with high performance and economy (Hompel & Schmidt, 2007). The advantages of inserting automation in warehouse operations include the following:

- Improved system performance (higher transhipment rates and shorter order lead times);
- Quality assurance (error minimization when compared to human labour and deadlines accomplishment);
- Cost savings (return on investment in a medium to long term, depending on the degree of automation);
- Relief of personnel from uniform, strenuous activities (more ergonomic positions and fewer repetitive and labour-intensive tasks).

Despitefully, automation does not always make sense and a careful and meticulous approach and study of the problem must be carried out on this field. Automation is generally associated with high initial investment cost and sometimes manual solutions may be more simple or economical. For that purpose, the automation of a process requires target values that will then define the desired procedure, with the information being possibly stored in the system or by an operator independent of the situation (Hompel & Schmidt, 2007).

The first automated warehouses were introduced 50 years ago, where the automation was mainly focused on pallet warehouses for increasing storage density. Later, mini-load and order picking warehouses were also automated (de Koster, 2018).

In general, automation in warehouses has received little research attention (Baker and Halim, 2007) and it is still only developed to a limited extent once large and long investments are necessary (Moeller, 2011). Inside the automation possibilities in warehousing, they can be divided in four main functions – consolidation, picking, storage and transport - with the most common being shown in Figure 12 (Wang et al., 2010), which also indicates in which operation they are used.

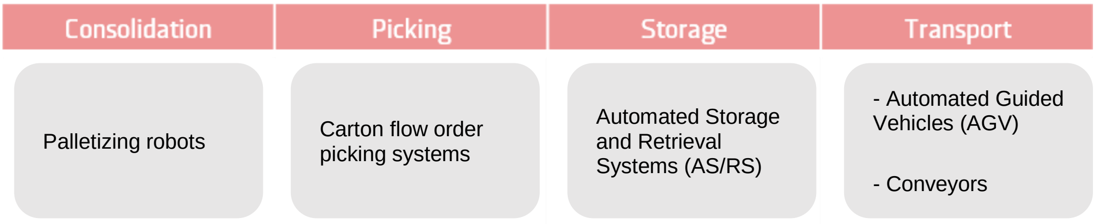


Figure 12 - Automation systems in warehouses

Consolidation, picking and storage automation are beyond the scope of this work and therefore excluded. In the present work, the possibility of inserting automation in the warehouse will uniquely stick to transport activities and in warehousing systems, a variety of automatic systems have been adopted to transport both materials and goods being the most common the automated guided vehicles (AGV) and belt-conveyor systems (Qi et al., 2018).

AGV systems are generally used for automatizing movement of goods among different locations and in an industrial environment (Stouten & Graaf, 2004). The two fundamental advantages of AGVs account for their flexibility and efficiency (Schulze & Wullner, 2006). These systems are proved to be suited for a wide range of tasks regarding material flow, guaranteeing that the value-added processes in the enterprises can run accurately. The technological development of AGVs increased their attractiveness for users concerned with issues such as modularity, standardization, energy concepts, navigation systems, automation of series vehicles and safety systems (Schulze & Wullner, 2006). The authors name the following substantial aspects for potential operators of AGV-Systems to profit from the experiences of other AGV-operators:

- Keeping appointment;
- Accomplishing efficiency statements;
- Testing operational availability;
- Reaction rate in case of disturbances;
- Replacement parts logistics;
- Replacements parts prices.

The other automated method that can be used for transportation of goods is a conveyor. The simplest conveyors steadily move loaded shipments along a fixed pathway, while passing junctions towards outbound stations (Boysen et al., 2019). However, the most common in warehouses are conveyors that integrate sorting systems in what is generally called Automated Sorting Systems (ASS). Boysen et al. (2019) point out four elementary characteristics of such systems: (i) ASS are fast; (ii) ASS handle a huge amount of shipments; (iii) ASS are reliable; (iv) ASS handle heavy and bulky items. On an operational perspective, ASS consist of one or multiple input stations for receiving, a network of conveyor segments and multiple outbound stations to collect the shipments sorted by different addressee (Boysen et al., 2019).

3.2 – Warehouse operations' literature review

Inside the existing literature on warehousing, researches published are mainly too problem-specific with each work describing and presenting different solutions and methodologies from case to case. A sound theoretical basis for warehouse layout design and operations management methodology still seems to be lacking in this field of study. To this purpose, they were selected the scientific papers available on the online platforms Google Scholar and Web of Knowledge that were most closely related to the one treated in this present work.

3.2.1 – KPIs in Warehouse Management

According to Rouwenhorst et al. (2000) a warehouse might be viewed through three different axes: processes, resources and organization. Products that arrive to the warehouse are treated through a series of processes (such as receiving, storing, picking and shipping) and resources refers to all the working material and personnel handled to operate a warehouse (from storage units, such as pallets or carton boxes to computer systems and human operators). The organization includes all the planning and controlling of the warehouse as a system. From this point, it is already understandable that designing a warehouse is quite a complex challenge once it is a system that includes a large number of interrelated decisions. Inside evaluating the efficiency of warehouse operations and structural layout changes, Anand & Grover (2015) name on-time delivery, capacity utilisation rate, overall equipment effectiveness, inventory turnover, customer satisfaction and overall labour effectiveness as the main operational KPIs (Key Performance Indicators). Chen et al. (2017) point out sorting accuracy, packing accuracy, customer service, space saving, rapid picking, timely shipping and reduced operational costs as the main performance indicators. However, despite not being as recent as other scientific papers found, the KPIs defined by Rouwenhorst et al. (2000) were perceived as the ones that were most closely related to the problem of this Dissertation. These authors stand out the following as distinguishable for a correct evaluation, keeping in mind that the relative importance of each criterion depends with the types of warehouses being treated:

- ***Order fulfilment quality (accuracy)*** – the main purpose of a distribution warehouse passes by storing products in order to fulfil external customer orders at the lowest running cost possible;
- ***Volume and mix flexibility*** – customer orders might be composed of a large number of order lines which represent a specific quantity of one particular product or of different types of products with small per order line quantities;
- ***Throughput*** – the maximum warehouse throughput is aimed to achieve by accomplishing the highest rate of items transferred through the warehouse;
- ***Response time*** – related with the maximum throughput, there is the commitment of expediting products with the lowest timeframe possible;
- ***Storage capacity*** – the ability of a warehouse to store products in a cost and space efficient way;

- ***Investment and operational costs*** – the ROI (Return on Investment) should be as high as possible while reducing at most the operational costs of the warehouse.

3.2.2 – Methodology for warehouse design

Several reviews of the literature have concluded that there is not a systematic approach that should be followed when designing a warehouse layout, from which they are highlighted the following:

- "A search of the literature shows that very few papers deal with the general warehouse design problem" (Ashayeri and Gelders, 1985);
- "In general, however, there is not a procedure for systematically analysing the requirement and designing a warehouse to meet the operational need using the most economic technology" (Rowley, 2000);
- "A sound theoretical basis for a warehouse design methodology still seems to be lacking" (Rouwenhorst et al., 2000);
- "A comprehensive and science-based methodology for the overall design of warehousing system does not appear to exist" (Goetschalckx et al., 2002).

With this absence of an accepted methodology, the most common is for warehouse designers to develop their own approach (Oxley, 1994). Regarding the most recent works published on this theme, Di Tria et al. (2017) provide a novel approach in the context of Big Data providing solutions to face issues related to the 5Vs (Volume, Velocity, Variety, Veracity and Value). Bimonte et al. (2017) provide a multidimensional model design using Data Warehouse (DW) and associated OLAP (On-Line Analytical Processing) algorithms. In fact, while there are many models for optimising individual aspects of warehouses, there is not a comprehensive design methodology that incorporates and supports all these design decisions into a complete warehouse system specification (Sprock et al., 2016), being each warehouse manager responsible for adapting its own methodology to its specific problem. As a result, after an intensive research, it was identified that the work provided by Baker & Canessa (2007) was the one that was most closely applicable to the problem at hand by providing an extensive review on the different literature approaches with the intent of providing a valuable structured approach and comprehensive methodology for warehouse design together with specific tools and techniques that can be used in each step of a general framework. A table with the methodological steps adapted to the problem at hand was developed and is shown in Table 2.

Table 2 - Methodology for warehouse design (adapted from Baker & Canessa, 2007).

Methodological step	Useful tools	Description
Define system requirements	Checklists Distribution network software	Definition of business strategy requirements and relevant constraints
Define and obtain data	Checklists Database models Flow charts	Extract data from company computer systems and summarise it in a useful way
Analyse data	Database models Spreadsheet models Flow charts	Analytic computation of statistics from database and design interpretation
Establish unit loads to be used	Checklists Survey existing operations Database models Spreadsheet models	Mathematical relationships to define accurate measurable units
Determine operating procedures and methods	Checklists Technology level assessment chart Standard work procedures Concept library	High-level procedures and methods for each function of the warehouse
Consider possible equipment types and characteristics	Spreadsheet models Decision trees Concept library Two-by-two matrix	Heuristic, analytic or simulation methods to approach equipment evaluation
Calculate equipment capacities and quantities	Spreadsheet models Historical KPIs Performance standards	Calculation of the needed resources´ measurable units
Define services and ancillary operations	Spreadsheet models Database models Equipment specification tools	By experience of warehouse designers define services and ancillary operations
Prepare possible layouts	CAD software Process flow software Simulation software	Formulate draft layouts with the aid of computerized softwares
Evaluate and assess	Simulation software Financial models Factor analysis	Validating operational and technical feasibility of proposed solutions
Identify the preferred design	Simulation software Business case Process flow Spreadsheet models SWOT analysis	Drawing together of all the above elements into coherent design

3.3 – Simulation & Modelling

3.3.1 – Conceptual approach

In order to evaluate the results proposed to be achieved, simulation will play a central role in the present work. It is the decisive tool that will allow to conclude the viability of the project at a reduced cost. As a technique, simulation is one of the most widely used in operations research and management science (Law & Kelton, 2000).

Prior to the simulation, it is necessary to define the system model to be studied. A system is regarded as a collection of interacting components that receives inputs and provides outputs for a certain purpose (Chung, 2003). For Schmidt & Taylor (1970), a system is a collection of entities that act and interact together toward the accomplishment of some logical end. Systems can be one of two types – discrete and continuous (Law & Kelton, 2000). In a discrete system, state variables change instantaneously in separate points in time, whereas in a continuous system, state variables change continuously in the course of time.

Maria (1997) defines modelling as the representation and working of a certain system of interest, in a way that it is similar but simpler than the system itself. Morris (1967) refers to modelling as a simplified representation of a complex system with the aim of providing predictions of the system´s performance metrics of interest as well as gaining knowledge and insight into the system´s behaviour. Models can be of different types (Altiok & Melamed, 2010):

1. Physical model: a simplified or scaled-down physical object
2. Mathematical/Analytical model: sets of equations and relations between mathematical variables that describe a certain workflow
3. Computer simulation model: program description of a certain system

The physical model is a representation by itself. The analytical *versus* the simulation modelling differ in such a way that analytical models call for a specific solution of a mathematical problem according to formulas and algorithms with the goal of obtaining performance measures of interest. Simulation modelling, however, calls for running (executing) a simulation software program with the aim of producing sample histories. The set of statistics computed from these histories is afterwards used to form the performance measures of interest (Altiok & Melamed, 2010).

For practical sense, one should design a model so that it faithfully captures the system behaviour only to the extent that the objectives of the simulation being studied demands (Zeigler et al., 2000). Combining the two concepts, a simulation model is a set of instructions (rules) with the purpose of generating Input/Output behaviour (Zeigler et al., 2000). Chung (2003) presents a simpler definition, pointing that simulation modelling and analysis is the process of creating and experimenting with a computerized mathematical model of a physical system. According to Law & Kelton (2000), in a simulation a computer is used to evaluate a model numerically, and data is gathered in order to estimate the desired characteristics of the model.

Simulation is commonly used before an existing system is altered and/or a new system is built so that the chances of failure to meet specifications are reduced, unforeseen bottlenecks eliminated, under and/or over-utilisation of resources prevented and system performance optimized (Maria, 1997). Behind these various advantages and utilities of using simulation modelling, Altiok & Melamed (2010) point out the following as the most motivational strands:

- Economic considerations;
- Evaluating system performance under ordinary and unusual scenarios;
- Predicting the performance of experimental system designs;
- Ranking multiple designs and analysing their tradeoffs.

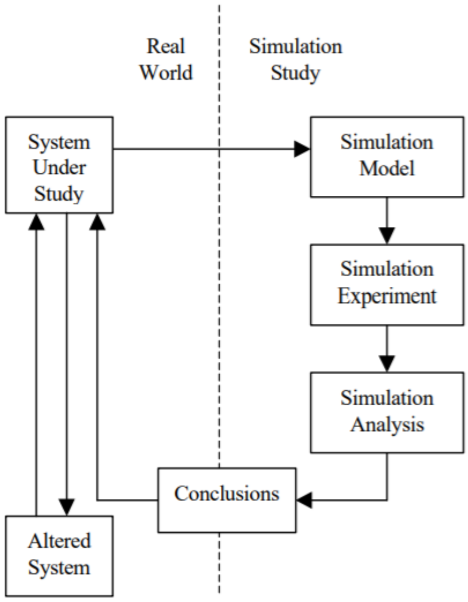


Figure 13 - Simulation and Modeling Steps

3.3.2 – A tool for Warehouse Management

Despite being still in development, the simulation tool has already been proved, in the past recent years, to be useful regarding warehouse management with some interesting researches published. Lerher et al. (2015) provide a simulation-based performance evaluation of shuttle-based storage and retrieval system (SBS/RS) for increasing the throughput capacity of the system. The results provided by simulation showed that SBS/RS are effective in reducing the cycle time as well as showing a large improvement by increasing the throughput capacity. Altarazi & Ammouri (2018) propose a concurrent simulation-based design of experiments approach of manual-order-picking warehouses with the statistical analysis of the simulation results showing that horizontal layout was preferable to other types of layout, small sized warehouses perform better than other large sized and recommending using high throughput for traditional layout-small sized warehouses. Peixoto et al. (2016) used discrete simulation technique for supporting the redesign of an automated warehouse system of the Brazilian Air Force unit. Using ARENA software, the results showed that the use of simulation tools not only allows the assessment of the impact of the new sorting equipment but also to test various warehouse management strategies that could be adopted in order to ensure the desired throughput levels. The authors end up concluding that the flexibility of the simulation to address several complex management issues simultaneously was preponderant to achieve the results proposed.

Bechtsis et al. (2018) provide an effective review directly related with the purpose of this Masters Thesis by providing a framework for developing highly customised simulation tools that support an effective integration of automation in supply networks.

Simulation is a continuously evolving field of research with undoubted contribution to the progress of manufacturing system (Mourtzis et al., 2014). With this, a vast number of software tools are available and can be clustered into the following five categories represented in Table 3.

In the present work, AnyLogic was the chosen software to be used in the project to simulate the operations and study its effects once this is the software provided by Worten. This specific simulation modelling tool uses three methods – discrete event, system dynamics and agent-based (Grigoryev, 2016). According to the same author, in simulation modelling, a method is a framework used to map a real word system to its model. In a discrete event modelling, a sequence of operations that agents perform is modelled as a process. Graphically, the model is specified as a process flowchart where blocks represent operations, initialized by a *source* which generates agents and injects them into the process, ending with *sink* blocks that removes the agents at the end of the process. This is the simulation method that will be used to address the problem at hand of this present work. System dynamics models are usually used in long-term, strategic models assuming high levels of integration. They represent people, products, events and other types of discrete items by their quantities. Agent-based modelling is a relatively new simulation method triggered by the desire of gaining deeper insights into systems that traditional methods do not capture well, by having insights into how the system´s objects behave.

Table 3 – Categorization of software tools and platforms used for simulation in Supply Chain Ecosystems

Category	Software and Platforms
Discrete-event simulation software	ARENA SIMIO Flexsim Promodel PetriNets AutoMod AnyLogic
Robotics software	Webots-MATLAB ROS-middleware C++
Multi-agent software	AnyLogic JADE
Dedicated vehicle control software packages for intralogistics	openTCS Vendor Specific
Object-oriented programming languages	C++ JAVA

In an industrial context, simulation software usually has a 3D add-on functionalities for precisely represent movements of machinery or any other physical object (Bechtis and Moisiadis et al., 2017). The use of general programming languages is continuously increasing in intra-logistics services due to the one-to-one correspondence between physical objects and their digital representations (Bechtsis et al., 2018). As a result, objects are easily extended, reused and diversified while the maintenance requirement of the software significantly decreases.

It is concluded from the Literature Review, after a general explanation of problem-related concepts, that the methodology presented in Table 2 will give support to the Methodology design of this Masters Dissertation. Additionally, the use of simulation tools in manufacturing sectors and Supply Chain Management is, after all, continuously growing and assist in the analysis of the expected sustainability impact of the insertion of automation in facilities such as warehouses.

Chapter 4 – Simulation

In this chapter, with the insights from the Literature Reviews developed, it is firstly defined the methodology to approach the problem at hand. Afterwards, they are presented the Key Performance Indicators (KPIS), objectives, restrictions and assumptions of the simulation models developed, which are subsequently detailed.

4.1 – Methodology

In this chapter, with the insights obtained from literature reviews and experiences from its authors, it is finally delineated the methodology to address the problem and present a final reliable, efficient and profitable solution. For the purpose of the methodology proposed for this Dissertation, the project phases defined by the company will be followed. As said before, it will be essentially focused on simulation for data treatment (Step 4 – see Section 2.5) in order to obtain the results proposed. Financial analysis and validation are out of the field of the present work, with the focus being on the operational improvement.

Being responsible for proposing a new operational flow and micro-layout of these four areas, it was assumed at the beginning of the work the intention of inserting PBS flow in these areas and that there was the possibility of inserting automation systems to improve work efficiency. Between the advantages mentioned, the main ones identified are (i) no need of contracting temporary operators for high peak seasons; (ii) no need of vacations' planning and medical casualties; (iii) higher efficiency always assured and not operator-dependant; (iv) maximizing working stations´ productivity by lowering waiting/idle times of operators (while they are waiting for work to get to them). Whereas the two main drawbacks were identified as: (i) high investment and maintenance cost; (ii) high dependency on automation systems (if they fail, all the operation stops).

It was defined that for the design of these areas, it should be proposed a solution of the micro-layout of the four. However, the possible insertion of automation would always be made in two phasis, due to the high investment inherent to it – a first implementation of the most critical areas, where it is identified the highest rate of operational inefficiencies and a second implementation of the remaining areas. With this, the results of the simulation models will be focused on the critical areas – PTZ and PTL – once these are the ones that will suffer the greatest impact of the integration of the PBS flow in this zone of the warehouse and the most changes in terms of layout and operation. Also, a different location of the operation areas in the warehouse by itself impacts the overall working efficiency. Therefore, for this first study phase, Online and PTS will be moved to their new locations still maintaining their current operating structure and processes.

The proposed methodology is divided in three main parts: firstly the simulation of the *as is* scenario, followed by the *to be* scenario and finally the comparison between both scenarios in order to take adequate conclusions of the solution presented. The input of both models will be the same (data from the month of November 2018), so, the comparison will answer to what extent would the drawn solution improve the overall operations´ efficiency. Each of these phases is then subdivided in distinct steps – the proposed methodology is presented in Figure 14.

In terms of simulation, it is adopted a backward methodology: outputs are firstly defined followed by the parameterization of the inputs. This is, after the representation of the model with standard inputs (such as fixed travel-times or rates) in order to keep the work results-oriented, the outputs intended to be obtained are clearly outlined so that the inputs, accurately defined afterwards, are correctly driven towards the achievement of the results. As Zeigler et al. (2000) proposed, one should design a model so that it faithfully captures the system behaviour only to the extent that the objectives of the simulation being studied demands – see Section 3.3.1. In a practical sense, taking as example the need of correct sizing a buffer to which pallets arrive (result), it is not mandatory to know for the purpose of this work the exact path that that pallet follows to reach that buffer but yes the travel time it takes. With this being said, the correct metrics parameterization in this case would be travel time and not distance.

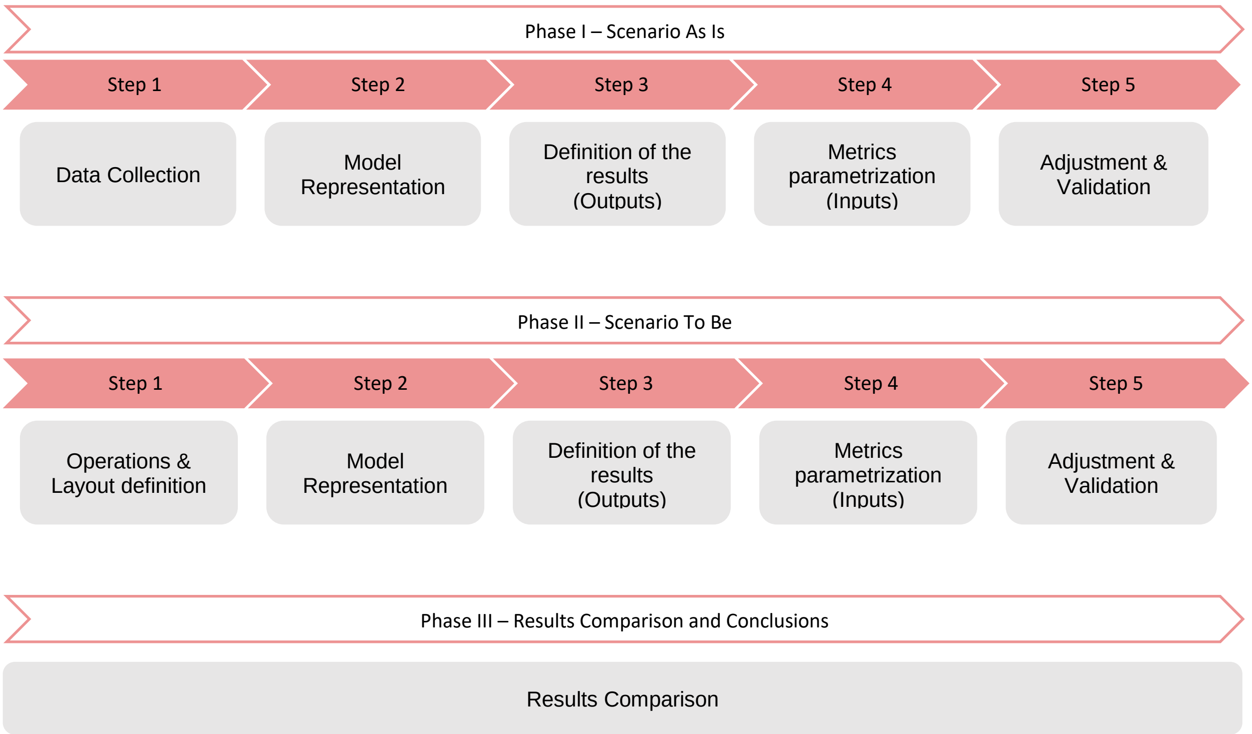


Figure 14 – Methodology

Phase I – Scenario As is

This phase has the purpose of correctly represent the operations as they are currently in the warehouse.

Step 1 – *Data collection:* In order to start an adequate simulation model, it is first necessary to collect the data needed. In this case it is referent to November 2018 of the operations PTZ, PTL, Online and PTS.

Step 2 – *Model Representation:* Having already clearly outlined how the operations work, the flow diagrams already represented will serve as starting point for the representation of the model in the simulation software. The interaction between activities, decision nodes and flows will aid the representation of the simulation blocks and flows between them. Using AnyLogic software, it is advanced to the simulation of the as is scenario. The model is outlined.

Step 3 – *Definition of the results:* Afterwards, it is started to point out the results that are desired to be obtained with the simulation so as to not lose the focus of the work and to develop the model in agreement with them.

Step 4 – *Metrics parameterization:* With the outputs clearly defined, it is necessary to correctly parameterize the metrics as inputs, this is, correctly measure times, distances and rates of the model.

Step 5 – *Adjustment & Validation:* Finally, the necessary adjustments will be done, results are obtained and the model is validated against the real record of occurrences in November 2018.

Phase II – Scenario To be

Step 1 – *Operations and layout definition:* Several operational possibilities were outlined in brainstorming sessions. Afterwards, market supply availabilities in terms of equipment were analysed and meetings for discussing the results to decide the best micro-layout proposal. Afterwards, it is proceeded to the representation of the 3D conceptual model of the proposal using Sketchup software, in order to correctly define the number of working stations and development of the operational solution, according to the macro-layout space restrictions. The remaining steps follow the same approach as in Phase I.

Phase III – Results comparison & conclusions

Results from both scenarios are compared and operational validation is concluded.

4.2 – KPIs & Objectives of the Simulation Models

Before proceeding to the representation of the simulation models themselves it is firstly necessary to define the KPIs of such models. In Chapter 3, they were clearly outlined the KPIs in warehouse management, which, although directly inter-dependent, can be divided in three main groups: Storage capability (volume and mix flexibility, storage capacity), Flows and operations efficiency (order fulfilment quality, throughput, response time) and Profitability (investment and operational costs) – see Section 3.2.1. After meeting with the company´s boards to establish priorities within the time frame of the whole project, it was defined that the Flows and operations efficiency indicators were the first mandatory desired results to be achieved, followed by Storage capabilities and finally profitability of this specific project. This was due to the fact that the macro-layout is already defined and approved and once operations zones take its new places, the first approach is to define how they are going to work, followed by the adaption of the storage areas to these new working flows and, finally, validate the financial budget for this overall project. The KPIs defined for evaluating the developed simulation models were then focused on the Flows and operations efficiency, still orienting and bearing in mind that storage capabilities are the next step for future work on these models. The company demanded then to be tested in the simulation models and micro-layout proposal the possibility of integrating the PBS flow (see section 4.1) in these operations – PTZ and PTL – once in terms of efficiency/productivity, in the case being studied, it is already proved that bulk picking is by far preferable to batch picking, which can be understood by this simple example: considering product A was ordered by stores 1, 2 and 3, for the PBS flow, on operator would have to go to that pick location that has product A stored two times, once this operator can only transport two pallets/stores at a time. In the case of a PBL flow, the operator would have to go only once, because the sorting by store would be done afterwards. Apart from this intention, as said before it was defined that automated systems could be inserted if proved to reduce operational inefficiencies. Taking this into consideration, and once the final and main purpose of this project is reducing operational cost they were defined as KPIs of the simulation models the operational efficiency (1), the required number of operators to perform the activities (2) and the operators occupation rate (3). With this, it is intended to prove that with less people (which means less cost) it is possible to improve the operational efficiency, measured by the time it takes to fulfil the demand, through a better integration of the flows between processes/activities of these zones and higher occupation rates. These KPIs can be divided in the specific and detailed objectives – see Section 1.2 - presented as follows:

- Accurate representation of the flows and operations of PTZ, PTL, Online and PTS working zones of the warehouse as they occur today on its corresponding locations;
- Propose of a new micro-layout of these zones and test it regarding the corresponding restrictions of their new locations in the warehouse, insertion of the PBS flow and possible insertion of automated systems to remove operational inefficiencies;
- Present and compare results of both scenarios concluding, if possible, operational validation of the project.

4.3 – Restrictions & Assumptions of the Simulation Models

When one designs a simulation model, it is necessary to correctly define the restrictions inherent to the system as well as the assumptions made throughout the development of such model. On behalf of the restrictions of the models, they were defined the following:

- The demand is restricted to the information available in internal database of the company;
- In the *As Is* scenario the number of operators used on the model is restricted to the actual number of operators currently working in these functions at the company;
- In the *To Be* scenario the number of operators is determined by eliminating transporting operators and adding new operators to new functions based on the expected necessities of the scenario;
- The only source of resources used was the number of workers (machinery was not considered);
- Once the new micro-layout of each of these zones has not yet been approved, the scenario *To Be* focuses on the increase of capacity but not in additional factors such as stores distribution in PTL sectors, which require further detail study.

In relation to the assumptions of the models, these are presented as follows:

- The distribution of stores in PTL sectors remained the same from the *As Is* scenario to the *To Be;*
- The conveyors speed in the scenario *To Be* is equal to the one of the unique conveyor in the warehouse at the date of today present in the online operations area.

4.3 – Scenario As Is

4.3.1 – Data Collection

The data collection is one of the most preponderant parts of a simulation once it is the first step/approach that will influence both the design and results of the model. An incoherent collection of data might result in disruptive outputs that can lead, in extreme cases, to unrecoverable investments and operational losses. In order to accurately collect the data for this warehouse simulation model, it was adopted the methodology shown in Figure 15.

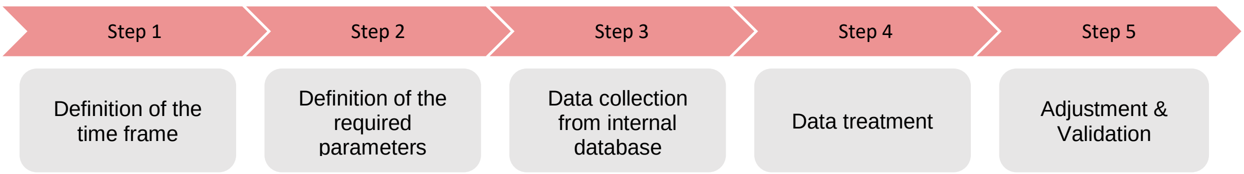


Figure 15 - Methodology for Data Collection

Step 1 *– Definition of the time frame*

Currently, the work force, in terms of number of operators working at the warehouse, varies according to the different operational demand peaks - in high demand seasons, temporary operators are subcontracted in order to fulfil those specific requirements. There is, then, a fixed number of operators in each team to which are added temporary operators when a higher demand so requisites. In terms of seasonality, the time unit measure used by the company is one month and Worten defines three different operational demand variabilities: low, medium and high.

- Low demand season (*February to May*) – this is typically the lowest demand season with the sales volume being low and extremely varied;
- Medium demand season (*June to August*) – in respect to summer and holidays, this season represents an increase in specific and varied products selling;
- High demand season (*September to January*) - starting with the back to school, which has considerable impact in school-related articles such as calculators, this season propagates until the starting of the preparation of stores for black Friday in October. After the black friday it proceeds to the Christmas demand peak ending in January.

As said before, it was assumed at the beginning of this project that automation could be inserted in the operation processes of the zones being studied. Once automation has to be programmed to work in all seasons it has, at the worst case scenario, to be able to work in the highest peak season. According to historical data, inside the high demand season, the month that typically represents the greatest sales volume is November, with the month of November of 2018 being the one in which the company registered the greatest sales volume that there is record. By assuring that automation is capable of satisfying the demand in this month, it will be able to work during the remaining seasons. Bearing this in mind, the data collection will correspond to the month of November 2018 – the last highest peak season in Worten's history. This data will be used as input for the simulation experiments of both scenarios

Step 2 *– Definition of the required parameters*

The data collected will serve as input to the model and will influence its output, that is why it is firstly mandatory to differentiate possible input data. The simulation model being studied will contemplate different flows – PBL and Online. For that reason, both are treated separately only converging when both flows cohabit – in the PTS operations area.

Regarding the PBL flow, keeping in mind the simulation tools requirements, the first purpose is to obtain data by SKU. The first field designed to obtain was, then, the arrival date and time of each SKUs. Once the model will be run for one month, instead of generating incoming agents through a statistical distribution or pre-defined arrival rates, because that information is available at real time by SKU, then this information is extracted. The first conditional node of the PBL SKUs flow (see Appendix 2) is its preparation zone, this is, from where it came – whether from reception or from stock. Following this flow, it is necessary to know the SKU´s volume, once this will influence the amount of units that are allowed to be transported and stored at the same time in different supports such as pallets, totes or boxes. Each SKU accounts for a unique ID of a certain item, which is to say that there might be more than one unit of the same SKU. For that reason, it is extracted the number of items of each SKU. The PTZ operations area, serves as an intermediary operating zone where the articles are sorted by PTL sectors (or, in the case of a volume higher than 6L, sent directly to PTS) so, by knowing in which PTL sector an SKU was prepared, it is possible to know that in the PTZ it was sorted to that sector. Finally, the PTL box number does not correspond to the store location in PTS, once it is a physical location ID of that box. It is then necessary to know which store ordered that SKU. By knowing in which store box of which PTL sector an SKU was prepared, as well as the corresponding system number of the store that ordered that SKU, it is possible to match both. The PTL sector in which the SKU was prepared as well as the PTL store location the SKU was placed in and the store number that ordered that SKU are then proposed to be extracted from internal database.

The operations in the Online flow work not by SKU but by customer order. This is a changing in the working object when compared with the PBL flow and the primary reason for treating both in separate ways. While the stores' business of Worten has been growing but at a low percentage rate (to the extent that we can use historic records to predict future month´s sales forces) the Online business unit of Worten is growing exponentially every year. The first main difference is, then, that this flow will not be worked with real data but with forecasted data based on historic records of the company as well as historic and forecasted expected growth. For that, several tables are required:

tbl_volumes: historic data of the orders volumes by day;

tbl_hours: historic data of how the percentage of total orders placed of each day is spread through the different hours of the day;

tbl_orders: information contained in the orders such as if it was purchased by site or in store, if is mono or multi, if it is to be delivered in store or at home, etc;

tbl_ptl: store/home delivery box locations of the Online PTL sector;

Growth: expected growth for this specific business unit.

***Step 3** – Data collection from internal database*

The data collected was acquired after Worten provided access to internal documentation, by programming and running an SQL statement in the software program ORACLE SQL DEVELOPER. Through its use, the information referent to the month of November 2018 was extracted – for the PBL flow in the format of a Microsoft Excel table and for the Online flow in the format of Microsoft Access tables, both of them from the archive contained in the system´s tables. The Excel fields extracted are shown in Table 4.

Table 4 - Excel fields extracted from internal database

Excel Collumn	Description	Value type
Date of arrival	Date and Time the SKU entered in the warehouse	*Date*
Preparation Zone	if the SKU prepared came directly from reception or from stock	*String*
SKU Description	SKU description	*String*
Unit Volume	SKU volume	*Number*
Total pulld	Number of articles prepared of that SKU	*Integer*
From Loc	PTL sector in which the SKU was prepared	*String*
To Loc	PTL store location in which the SKU was put in	*String*
Store Number	Store that received the SKU	*Integer*

1. **Date of arrival** (from the 1st of November until 30th of November): by day, in which a specific article was prepared during that month;
2. **Preparation Zone** (Reception or Stock): if that article came directly from reception or it was stored (from stock);
3. **SKU**: description of the SKU
4. **Unit Volume** (in cm^3): volume of the article
5. **Total pulld** (in units): number of units of that sku that was prepared
6. **From Loc** (PTLPQ, PTLMD, PTLG1, PTLG2, PTLG3, PTLG4, PTLG5, A88B): sector in which that sku was prepared – in the case of a PTL area, in which of the PTL sectors it was prepared; in the case of a PTS area, the sector code is A88B;
7. **To Loc**: store location in the PTL sector in which that sku was put in;
8. **Store Number**: store location in the PTS area – in the PTS section, as explained previously, there are pallets spread on the floor with each pallet corresponding to a specific store in which

the products prepared from various flows converge (for example, in a specific pallet, closed boxes coming from PTL sectors are put together with above six liters products that were directly stored there). Each pallet/store has a specific location associated;

This Excel table was imported into the simulation software AnyLogic and will serve as input to the model.

Step 4 *– Data treatment*

During the development of the simulation model the Excel worksheet had to be adapted and modified in certain points in order to match with the model drawn. Those adjustments will be explained in the course of this work.

Step 5 *– Adjustments & Validation*

Process of validation of the adjustments made.

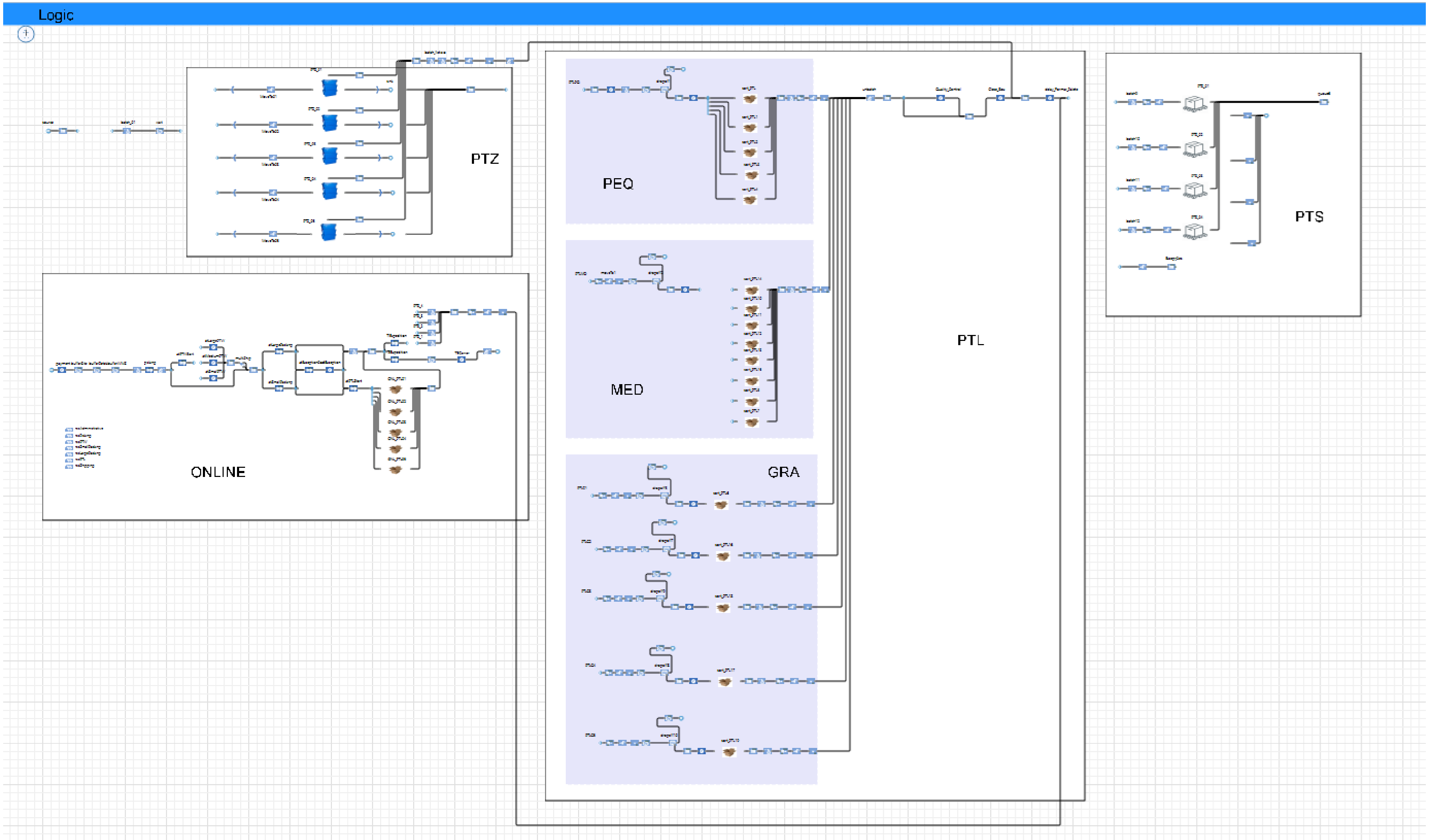


Figure 16 - As Is Simulation Model

4.3.2 – Model Representation

The model representation of the As Is scenario, represented in Figure 16, is divided in 4 different phases, each one corresponding to each of the four zones. Sequentially, PTZ was firstly represented, followed by PTL and PTS. Afterwards, Online was integrated in the system. This methodology is shown in Figure 17.

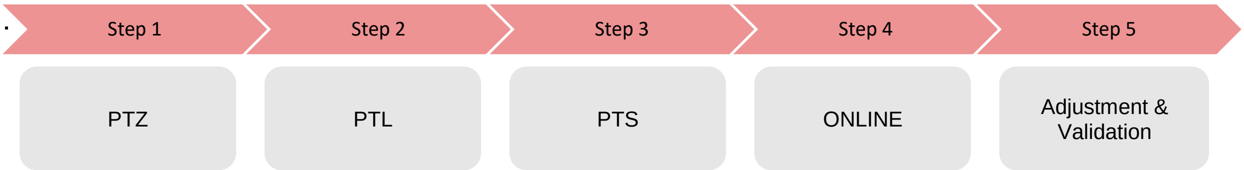


Figure 17 - Methodology for Model Representation

The first step was defining the model time which was considered to be hours. The simulation time was then scheduled to be from 01/11/2018 to 30/11/2018, as mentioned in the previous section.

The first agent is defined as SKU (**Agent 1 – SKU**), through the Excel table that is imported to the model. The table columns are defined as the agent´s parameters. The first block to be represented is the source block. Uploading data from de Excel table, the SKU agents are created according to its date of arrival – by reading the column "date of arrival" and matching it with the current simulation time, the agents are generated accordingly (as well as to its quantity): they are generated the number of SKUs of the same type that are expressed in the column "Total Pulld". These SKUs are agglomerated in the sub-agent Population_Skus that records all the units created.

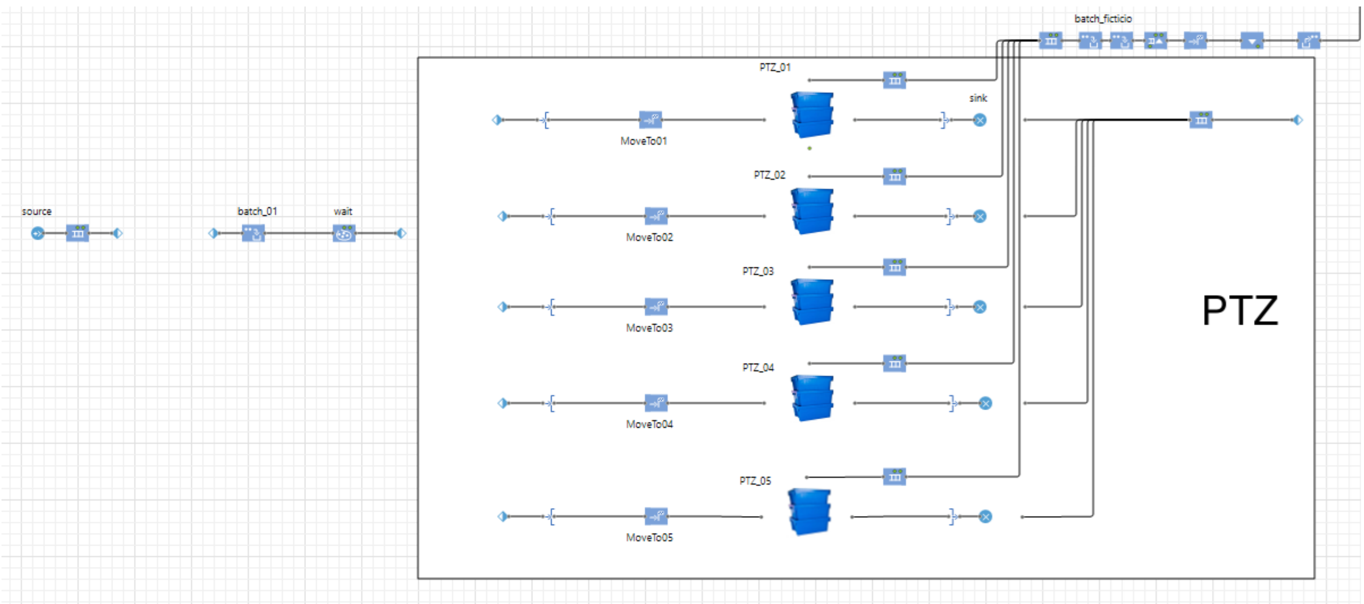


Figure 18 - PTZ model representation

After the source block, it is necessary to immediately divide the SKUs that are to be prepared in the PEQ sector from the others, once these do not pass by the PTZ operations area – they are sent directly to the PEQ sector. In the Excel table, it is added a column that retrieves index 0 if an SKU was prepared in a PEQ PTL sector and 1 otherwise. In the simulation model, this is represented by adding a conditional block that reads this new parameter of the SKU and separates it accordingly. Considering the articles that proceed to PTZ operations area, it is necessary to store the SKUs in pallets once that is how they arrive into this area. It is created a second agent: Transport_Support (**Agent 2 – Transport_Support).** This agent might regard to a pallet or a tote according to a defined function. A batch block is inserted receiving as input SKUs and converting to the output Transport_Support according to a volume limit. A third agent – PTZ – is created (**Agent 3 – Sort_PTZ**). The 5 PTZ working stations are represented (Figure 18) as well as the flows between them.

The flow inside each of these stations is represented in the agent PTZ as shown in Figure 19. With resort to a dropoff block, SKU agents are separated from the transport support pallet, and are sorted, one by one, to its corresponding PTL sector by reading this information on the agent´s parameter “From Loc”. The SKUs with a volume greater than six liters proceed directly to PTS.

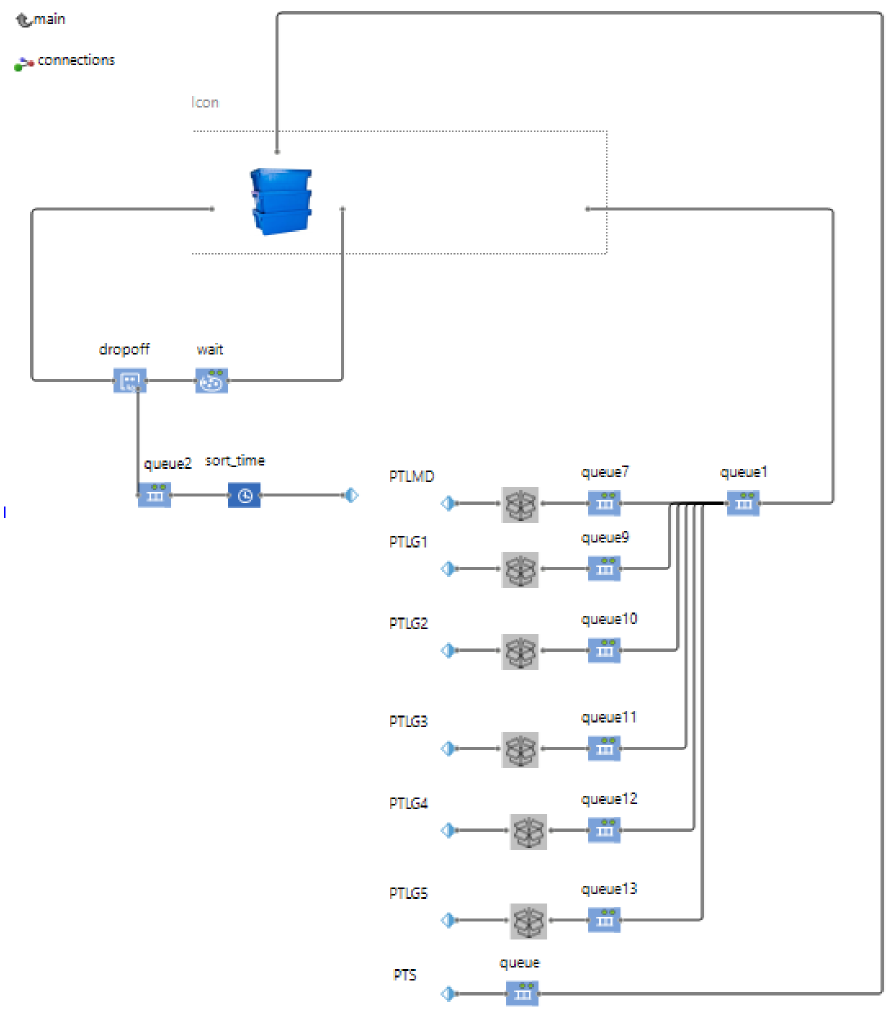


Figure 19 - Sort_PTZ agent

In the PTL area, they are represented the seven operating sectors – PEQ, MED, GRA1, GRA2, GRA3, GRA4 & GRA5 (Figure 20).

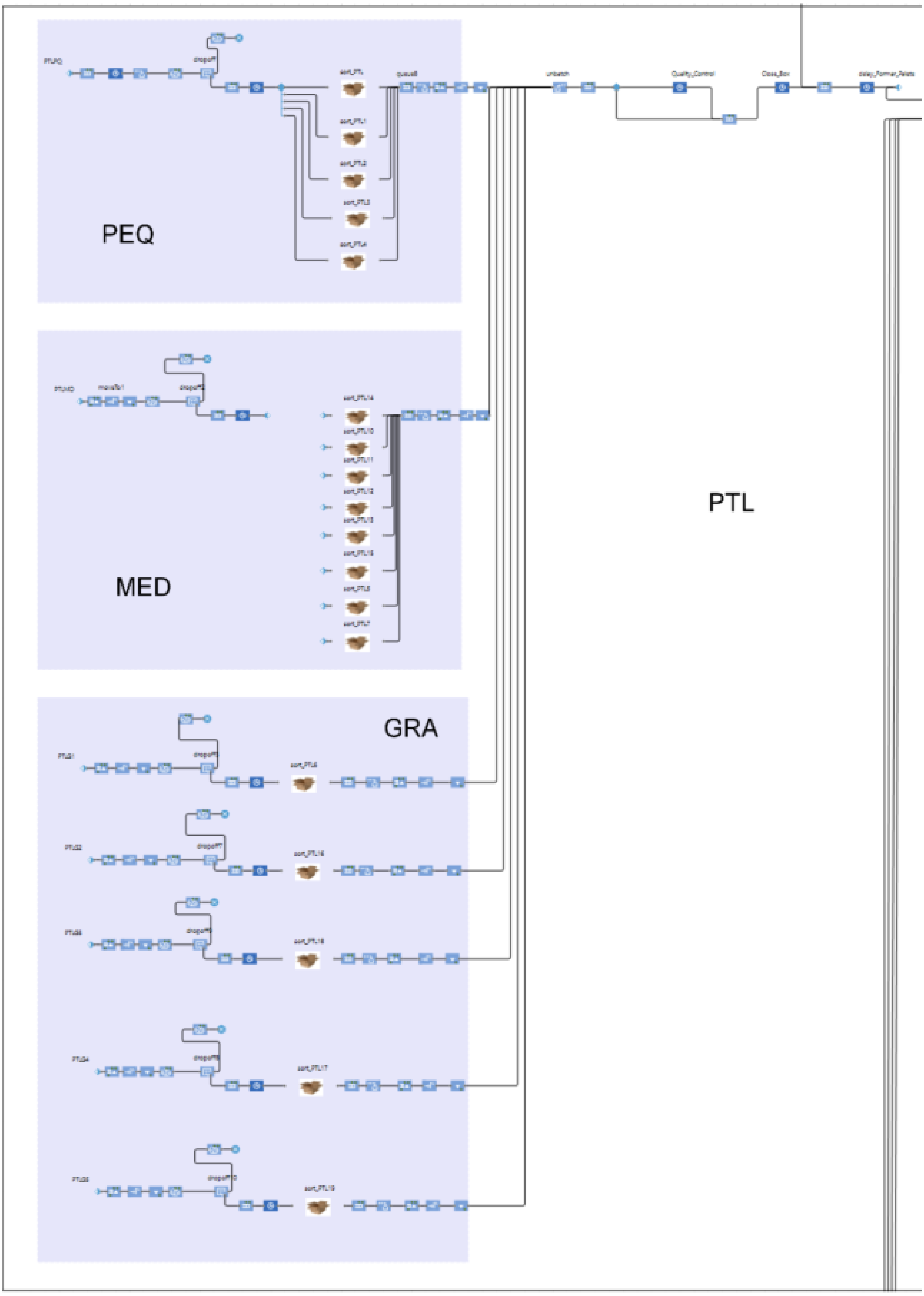


Figure 20 - PTL model representation

As explained in the previous section, the PEQ sector receives not totes but the SKUs directly from reception, which corresponds, in the simulation model, to the first conditional node that separated articles that passed by the PTZ operations area from the ones who do not.

In each of these sections it is represented the flow of the SKUs, namely the receival of a tote with articles inside and its sorting by the corresponding store location in the PTL sector. A new agent is created – PTL (**Agent 4 – Sort_PTL**). Here, another adjustment in the Excel table was needed: Worten sells products for over 180 stores, with most of them being present (this is, having a store box location) in each of the 3 types of PTL sectors – PEQ, MED & GRA. This would result in over 500 output nodes which would overcharge the software unnecessarily and slow its simulation run time. In order to overcome this excess of data reading, they were created fictional sub-sectors of the PEQ and MED PTL sectors. Each of the five GRA sectors has 36 store locations, whereas PEQ sector has over 150 stores and MED sector over 250 stores (once some of them are dynamic, this is, a certain box locations not always corresponding to the same store, being it possible to vary according to demand – these dynamic box locations account for low order stores, usually low sized Sonae stores to which Worten sells products, such as Gas Stations or small sized Sonae supermarkets, that occasionally order low amounts of products).

Taking as reference the GRA sectors, each PTL agent has 36 possible outputs each of them corresponding to a store box location. In the PEQ sector, PTL store locations range from 201 to 356. In the MED sector they range from 401 to 656. Sector GRA1 ranges from 1 to 36, GRA2 from 37 to 72, GRA3 from 73 to 108, GRA4 from 109 to 144 and finally GRA5 from 145 to 180. Playing with these ranges, GRA1 is given subsector 0, according to a function that evaluates if the store number is between 1 and 36; GRA2 is given subsector 1 (store number between 37 and 72), and so on and forth. This results that PEQ has five subsectors and MED has 8 subsectors, which, although in reality they correspond to a unique sector, for a matter of simplification these subsectors were created to differentiate the various store box locations. Figures 21, 22 and 23 show the model representations of PTL sectors PEQ, MED and GRA, respectively.

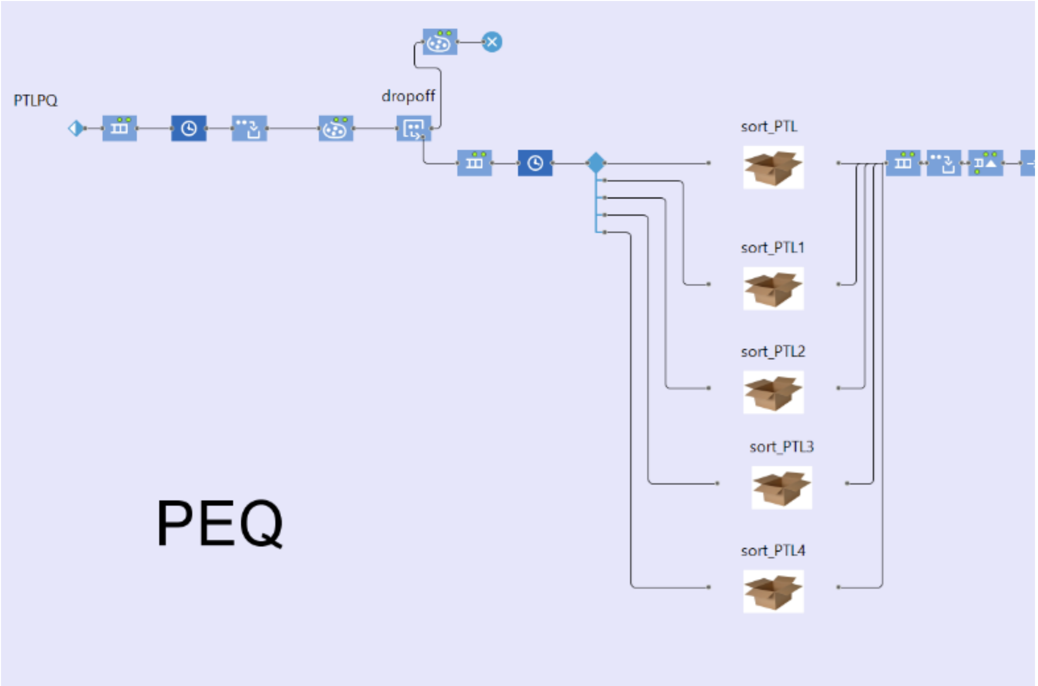


Figure 21 - PTL sector PEQ model representation

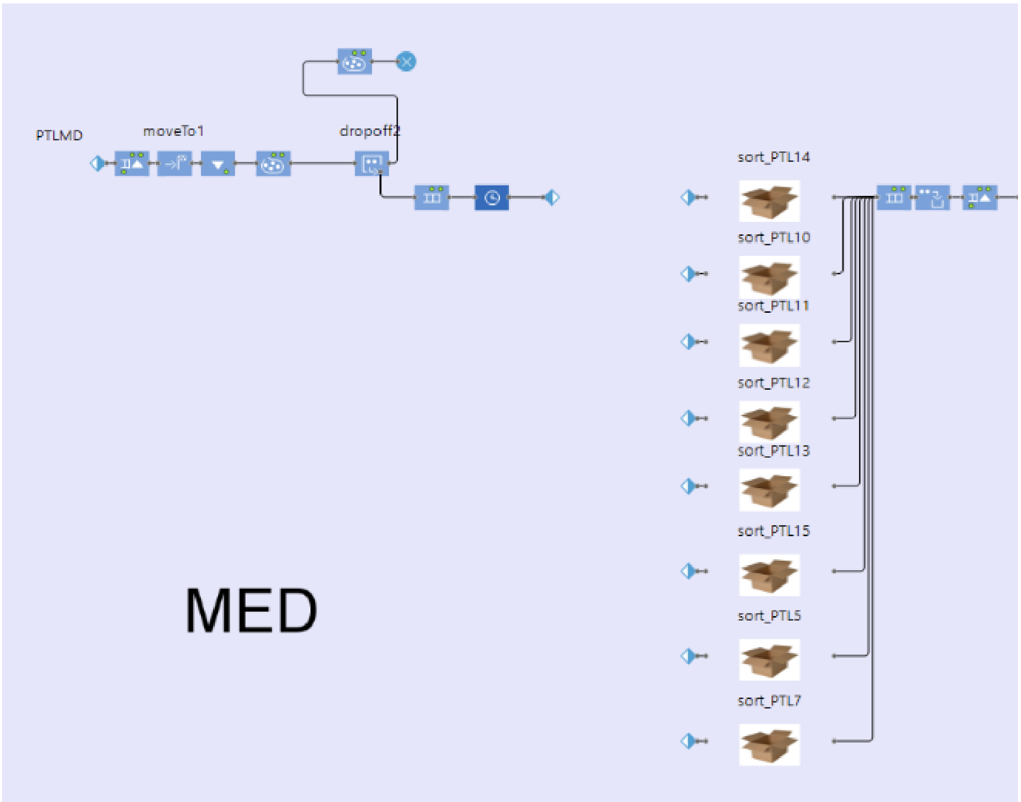


Figure 22 - PTL sector MED model representation

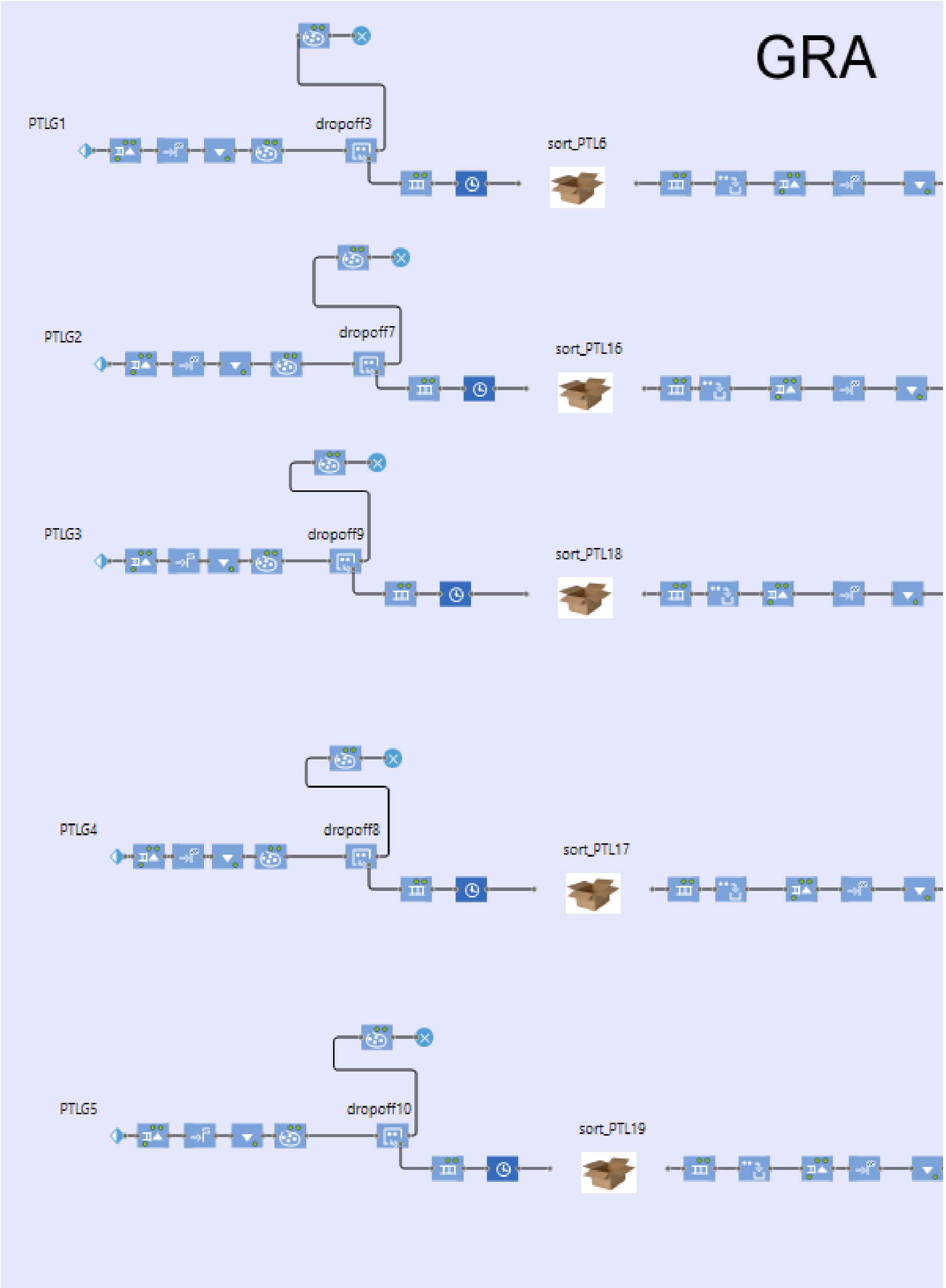


Figure 23 - PTL sectors GRA model representation

When a store box is full of articles, as said before, an operator pushes it and another operator is responsible for picking that full box and transport it to the PTS operations area. Apart from this casuality, there is a scheduled cut-off hour, from which all the boxes with articles inside are closed and transported to the PTS area once the trucks that are going to deliver them are about to arrive. Through this process, there is a quality control before proceeding to PTS, where random boxes are selected to check its quality – the boxes are opened, checked if the articles are not damaged and if all the articles supposed to be inside are effectively inside that box – for a matter of error report control and service quality. Afterwards, the boxes and the products with a volume higher than 6L that came directly from the PTZ operations area, are sorted for 5 possible outputs: each one of the four PTS corridors and an error output – this is, if something went wrong (might be articles missing, in excess, damaged, errors reading printed OLPNs, etc.). For the four PTS outputs, the boxes are stored in pallets that will be transported by an operator who will sort the boxes by its respective PTS store pallet location. The PTS representation is shown in Figure 24.

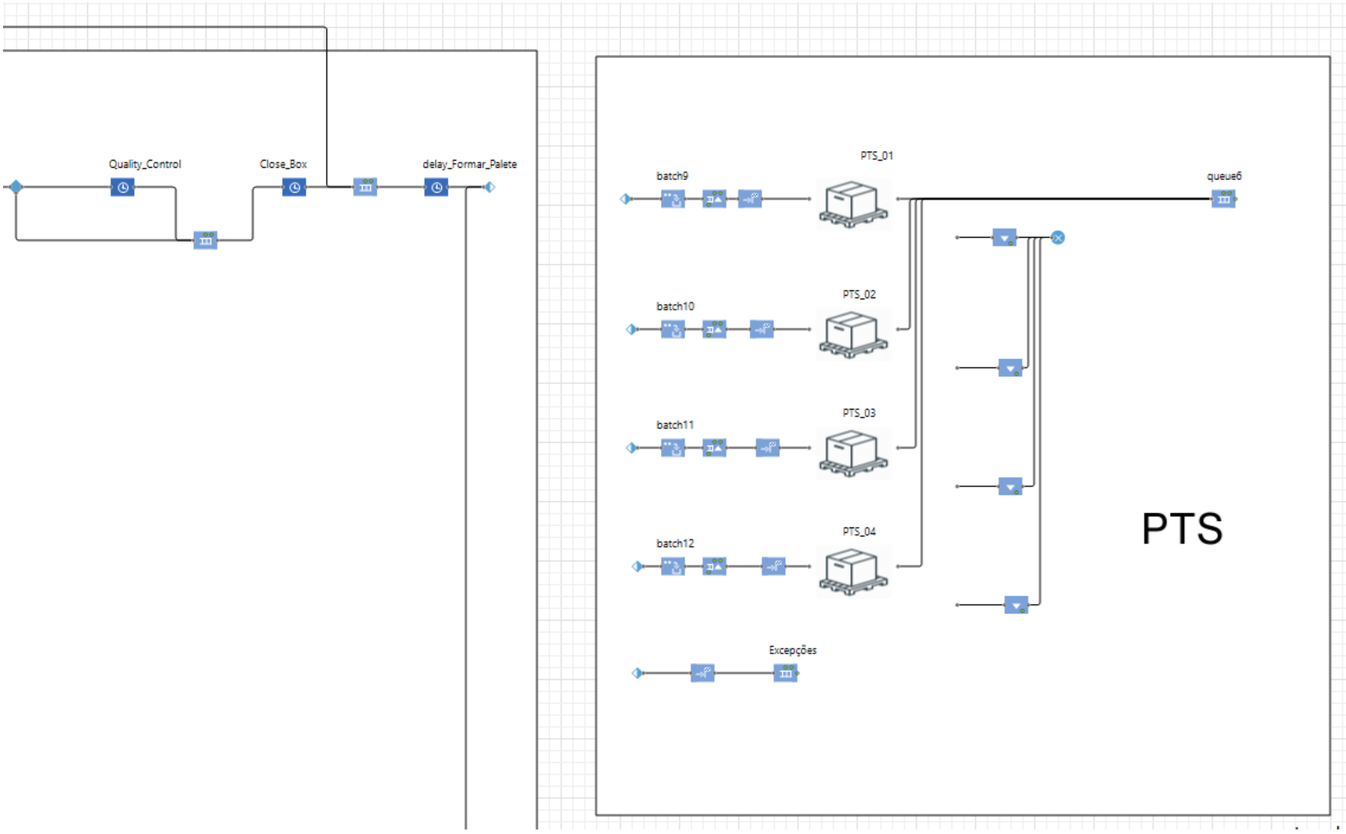


Figure 24 - PTS model representation

Such as in PTZ and PTL, a new agent is created – PTS (**Agent 5 – PTS**). Both the PTL and the PTS agents work in a similar way to the PTZ shown in Figure 18 – the number of outputs is what varies - they receive a batch with articles inside, the articles are removed from the transport support (in the case of PTZ and PTS it is a pallet and in the case of the PTL is a tote) and are sorted for its corresponding outputs according to the information provided by the Excel table.

Similar to these agents that unbatch articles, they are also created batching agents – slot (**Agent 6 – Slot**) and pallet (**Agent 7 – Pallet**). The slot agent accounts for the tote or box in which products are put in together (in PTZ or PTL operations areas, respectively) whereas the pallet agent accounts for the batching of boxes and articles coming from PTZ, Online and PTL operations areas. Both these agents work in the same way as represented in Figure 25.

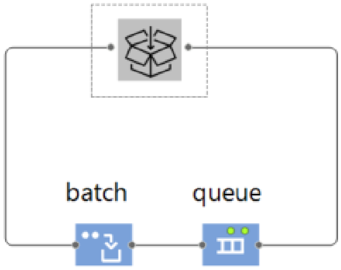


Figure 25 - Agent Slot

Regarding the Online flow, the first agent defined was the order (**Agent 8 – Order**). The source block will generate these agents by getting the quantity of orders volume from the table "tbl_volumes" for that simulation day and multiplying it with the percentage of the orders for that hour (tbl_hours) of the day and the growth parameter (Figure 26).

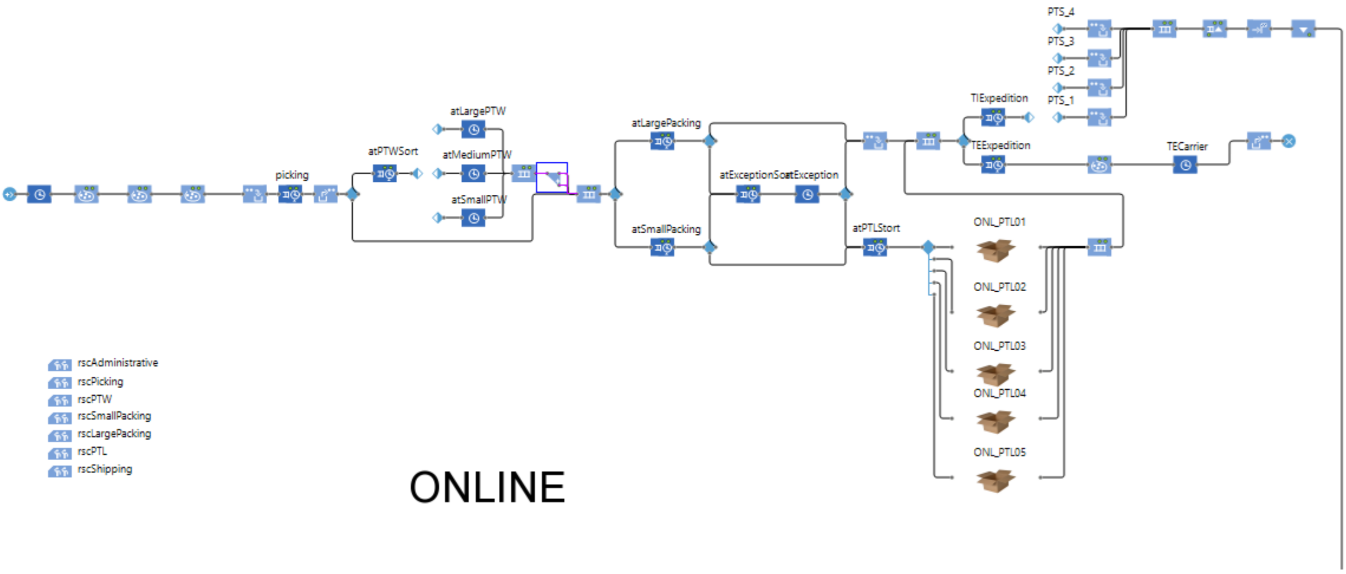


Figure 26 - Online model representation

The orders follow their natural flow: they arrive from picking, are separated between Mono or Multi orders and from Small or Large size. They are packed in the corresponding packing stations and proceed to the shipment zones. It is created a new agent – Shipment (**Agent 9 – Shipment**) – that corresponds to the orders ready to be expedited. In the case of large orders, each order corresponds to a shipment, this is, a batch with size 1 is used to transform one order agent into one shipment agent. In the case of small orders, they proceed to the Online PTL sector to be aggregated in boxes each of them corresponding to a common final destination (shipment) which might be a store or a customer home (in the case of home delivery). This Online PTL sector is divided in 5 independent sub-sectors each of them containing different stores/final destinations. The reasoning applied in this part of the simulation is similar to the one explained for the PBL flow and the agent is the same – Sort_PTL. However, instead of the agent Slot – that in PBL flow batches SKUs to transport supports – in this case it is created another agent – Slot_ONL (**Agent 10 – Slot_ONL**) – that batches orders to shipments. Both these flows – large and small shipments – are then sorted firstly in terms of transport operators – internal or external, depending if it is a home delivery shipment or if it is a store shipment and, in the second case, if the store has delivery window in that day or not (see Section 2.4.2.4) – and then, if they are to be delivered by internal operator, the shipments proceed to the Online PTS area where they are sorted in 4 possible outputs each of them corresponding to a different PTS corridor (in a similar process to the one explained for the PBL flow in the PTS reception area – see section 2.4.2.3). Finally, an operator is responsible for transporting these pallets to the PTS reception area where the Online flow converges with the PBL flow.

For this purpose, it is then necessary to create the resource agents, this is, the agent Operators. Two new agents are created – PBL (**Agent 11 – PBL_Operators**) and Online (**Agent 12 – ONL_Operators**) operators – as resource pools. These agents are then assigned to its corresponding activities and will play an important role on the output results, once their productivity improvement is one to be measured, evaluated and compared in both scenarios – As Is & To Be. Finally, there is the Main agent, automatically created by the system, where the simulation model, output results, functions, variables and parameters are represented (**Agent 13 – Main**). In Figure 27 they are represented all the agents generated in the simulation model.

After the representation of all the blocks and flows, adjustments to the model were performed and errors corrected until a correct simulation run was achieved.

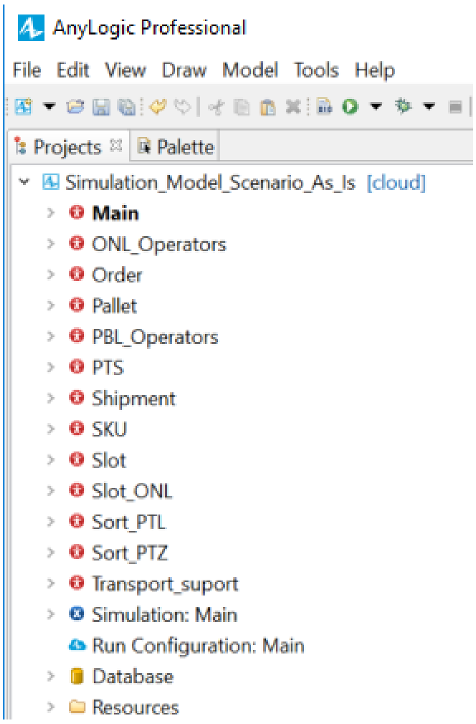


Figure 27 - Simulation Agents

4.3.3 – Definition of the Results

The present work proposes to study operational improvements and cost reductions by implementing automation systems in the warehouse operation flows. Keeping these main purposes in mind, it is now necessary to study and define the KPIs that will evaluate both models (As Is and To Be) and produce the output results proposed to be achieved. In terms of operational improvements, these require not only accurate resources management, allocation and productivity evaluations but also space management measures. Both are directly correlated, once the higher the working stations, the higher the number of resources and the higher the space required to perform these activities. This work approaches then a complex variety of variables and outputs that need to be distinguished at first hand. Once there are space restrictions to the new layout of the operations being studied, the first step is to differentiate between comparable outputs of both scenarios (As Is and To Be) in terms of operational productivities in order to evaluate the expected impact in the overall efficiency of the operations line (mainly related with KPIs referent to resources´ occupation rates and times required to perform the activities) and measurable outputs that will assist in the new micro-layout design (mainly in terms of space required to avoid bottlenecks and assure a correct functioning of the system as a whole).

There are three main output results desired to be achieved which vary in terms of purpose. These are Comparison Results, Designing Results and Support Results (Table 5). Regarding the first ones, these account for the results that will allow a comparison between both scenarios where the KPIs will be expressed in the resources dimensioning, occupation and cut-off hours. It is expected that with the implementation of automation systems in transport activities of the warehouse that substitute human workforce, the number of operators required will be reduced (which allows a cost reduction), their occupation rates become higher and the time required to perform all the activities as a whole will be shorter (once the new layout aims to approximate the activities with convergent flows in order to reduce transportation inefficiencies). The Design Results aim to provide outputs regarding space management and dimensioning. This is, once the four activities will be moved from its current locations and its flow process changed by the insertion of automation, the flow rates will be impacted and it is then necessary to know the space required for stopped product in order to avoid bottlenecks and assuring a correct functioning of the system as a whole. The Design Results propose to provide these outputs in the form of number of pallets, number of totes or volume required. Finally, the Support Results aim to provide cadence flows between areas for a first approach to possible automation suppliers in order to obtain budgets for the project. For the purpose of this work, once it is focused in operational improvements, the Design and Support Results will not be considered during the development of this dissertation once both require automation supplier´s integration in the project – the Design Results can only be considered after the automation suppliers define the system´s requirements in terms of space to implement the conveyors whereas Support results require automation suppliers´ specifications of which values are precisely required.

Table 5 – Simulation Results

Type of Result	Scenario(s)	Units of Measure	Purpose
Comparison	As Is To Be	Time Occupation rates Number of Operators	Improvement Performance Efficiency
Design	To Be	Number of pallets/totes Volume	Space Management
Support	To Be	Units/time	Automation Development

Comparison Results

In order to measure improvements on working time, it will be evaluated the total time required for closing the operations line. This is, at the time trucks start arriving and products have to be expedited, the operations stop and operators start preparing the loading of the trucks. This value will be measured with resort to a daily time plot, where the simulation will output the time it took, in each day, from the moment the operations stopped, until the production was ready to be expedited.

For the resources dimensioning, a histogram is created where the percentage of the total time is measured by number of utile working employees, for PTZ, PTL and PTS operations areas. Because the number of working employees is equal to the number of working stations, this is, taking PTZ as example, 5 operators for 5 PTZ working stations, this histogram provides information regarding what percentage of the total working time were all the 5 operators working at, only 4 operators working, 3 and so on and forth. This is also correlated with the Design results, once it might be an indicator of the quality of the stations/workforce dimensioning. It allows to conclude, for example, if only 5% of the total time are the 5 PTZ operators working, maybe it is because there is one working station that is not required, being possible to have only 4 working stations.

The same reasoning is applied to the transport operators, where it is evaluated the percentage of total time that these operators are actually working. Again, if this value is close to 100%, it might indicate that the workload is overcharged and might be the cause of lower occupation rates of other activities once these operators are responsible for feeding the different workstations. Automation systems that are being studied to be implemented might help in solving this hypothetical issue.

For the PTL sectors, they were created additional histograms to evaluate the occupation rate of each employee of each sector. This might also provide an indicator of the quality of the stores distribution by the different sectors. For example, if GRA1 employee occupation rate is close to 100%, this will be reflected in the buffer size of GRA1 and there might be a bottleneck present. At the same time, if GRA2 employee occupation rate is 50% there might be an improvement opportunity to review the stores present in both sectors and distribute the workload evenly in order to remove the bottleneck and match occupation rates.

The number of operators will be defined directly by eliminating the operators assigned to the transportation activities - this is, the operators responsible, for example, for transporting totes from PTZ operations area to the corresponding PTL sectors or for transporting pallets from the Online operations area to the PTS reception area - and the reduction in personnel possible to be achieved by inserting the PBS flow in these areas. This will be applied in both models – As Is and To Be – and the improvement calculated.

Design Results

Regarding the PBL flow, it is necessary to know the size of the receiving buffers of each zone, this is, taking as example the PTZ operations area, what is the required space in number of pallets for each PTZ working station to receive according to the rate by which the SKUs arrive (in pallets) to this area. For PTZ, PTL sectors and PTS they will be created time plots in order to observe the evolution of the buffer size over time as well as its peaks. This is configured in the simulation model by creating a variable that evaluates the size of the queues that precede each of these model agent activities with the maximum value that this variable took during the simulation time. This value will be proposed to be the size of the buffer. This output is required once automation systems will influence the arrival rates of agents to these stations by a theoretically faster transport.

For the Online flow, these outputs are not required once the automation systems to be implemented are only to drain objects and do not influence flows inside this area. The space required is the same as of the scenario As Is with this area being only moved from one zone of the warehouse to another.

However, these outputs require automation suppliers´ integration in the project, to provide information related, for example, with conveyors speeds which will affect the rate at which the objects arrival to the workstations and, then, the buffer sizes or required space to implement automated systems which will affect the space available for the working stations. Once these contacts have not yet taken place and that information is not available, these results will not be considered in this dissertation.

Support Results

Automation suppliers require information on flow and arrival rates in order to develop the automation systems. This is, for example, for a higher cadence of arrival of agents to one conveyor system, the faster must it be in order to drain these agents out so as to avoid bottlenecks. The same is applied to sorting systems. For that, values of cadences such as totes/minute that are fed from the PTZ operations area to the PTL sectors are required to be known by automation suppliers but, for the same reason as of the Design Results, only after initiating contact with them will it be possible to accurately define which values are demanded to be obtained and extracted from the simulation model. These results are then not going to be considered in this dissertation.

4.3.4 – Metrics parametrization

When designing a simulation model it is imperative to correctly define the inputs used so that they represent as close as possible the real system behaviour in order to obtain the correct results. When this simulation model was firstly defined, with the blocks and flows represented, the input parameters were not modified, with the values used being the software standards. In this phase it is started firstly by the definition of these input metrics taking as reference and basis the results defined to be obtained in the previous section. Afterwards, it is proceeded to the collection of the defined values and finally, these values are inserted into the simulation model (Figure 28).

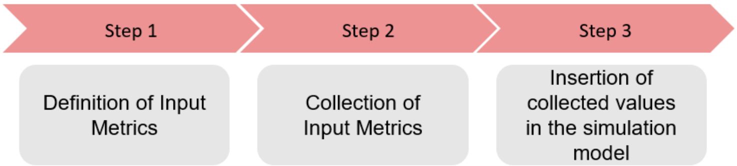


Figure 28 - Methodology for metrics parametrization

Definition of Input Metrics

Number of articles per transport support: how many articles can be stored in a pallet that arrives to the PTZ or number of articles stored in a tote that arrives to PTL sectors, among others;

Trip times: time required to move agents such as transporting totes from the PTZ operations area to the PTL sectors by the transport operators;

Delays: time required for specific activities, such as the close box time in the PTS reception area or the time it takes for a PTZ operator to pick a pallet and start sorting the articles;

Probabilistic events: percentage of boxes that are subject to Quality Control in the PTS reception area;

Operator´s productivities: time it takes, on average, for operators to do their work. This is, for example, the time it takes for a PTZ operator to remove one article from the pallet and place it in the corresponding tote;

Cut-off hours: defined scheduled for cut-off times. This is, for example, at 9 p.m. of each day, all the boxes with articles inside from PTL sectors are closed and transported to the PTS operations area, to be sorted. At the same time, articles from the online operations area start to be taken into PTS area, if intended to be delivered by internal operator.

Working hours: operators shifts´ schedules (which include breaks).

Table 6 provides the details on each metric.

Table 6 - Input Metrics

Type of Metric	Parameters	Units of Measure
Transport Supports Capacities	Arrival Pallets Capacity PTS Pallets Capacity Totes Capacity	Percentage
Trip Times	PTZ – PTLG1 PTZ – PTLG2 PTZ – PTLG3 PTZ – PTLG4 PTZ – PTLG5 PTZ – PTLMED PTZ – PTS Sorting PTS	Time
Delays	PTZ Start Up time A PTZ Start Up time B PTS build pallet time Close Box time	Time
Probabilistic Events	Quality Control Subjection Probability	Percentage
Operator´s Productivities	Sorting Time – PTLPQ Sorting Time – PTLMED Sorting Time - PTLGRA	Time/Unit
Cut-off Hours	PTZ PTL PTS ONLINE	Scheduled Time
Working Hours	Users Defined Schedules	Scheduled Time

Collection of Input Metrics

Regarding the Transport Support capacity, the dimensions of both transport supports – pallet and tote – were used. The pallets used at Worten warehouse are Europallets sized 1200 mm x 800 mm x 144 mm. Once the height of a Europallet is not considered for these calculations (it is not possible to store products there), it is possible to get storage area of 960 000 cubic millimetres. After running experiments on the field by measuring the height of the articles stored in pallets it was concluded that no pallet exceeds a maximum size of 1500 mm. Converting to volume, it was possible to get a maximum volume of 1 440 000 000 cubic millimetres. On average, the pallets get 80% of that volume stored with products with this corresponding parameter being set to 80% of the total 1 440 000 000. By reading the unit volume of the agent SKU available on the Excel input table, these articles are added to pallets according to this defined limit. In the case of totes, a similar reasoning was applied. For Trip Times, Operator´s Productivities and Delays these were collected on track, by directly measuring in various samples the time it takes, on average, for operators to complete these activities. In terms of Probabilistic Events, Cut-off hours and Working Hours, these values were provided by the Warehouse Operations Managers.

Insertion of the collected values in the simulation model

The Transport Support Capacities, Trip Times, Delays, Probabilistic Events and Operator´s Productivities were added into the simulation model as parameters whereas the Cut-off hours and Working Schedules were inserted as scheduled events.

4.3.5 – Adjustments & Validation

By multiple runs of the model, it was necessary to correct mistakes and observe if the model is actually working the way it is meant to work – if the functions programmed are correctly working as well as the variables and parameters registered and altered through time and the results being updated. The necessary adjustments were made to the model until being validated.

4.4 – Scenario To Be

From the new macro-layout defined and presented in Section 2.4.2, the first approach to study the Scenario To Be was to represent, using the 3D design software Sketchup, the four warehouse operations – PTZ, PTL, Online & PTS – in their new locations according to the space restrictions of these zones of the warehouse. Progressively, it was started to consider to possible micro-layout disposal of the different working stations in each of these four zones considering the company´s demands for the project. At the same time, possible improvements in each process step were considered throughout the development of this design model. This study was done in coordination with the Warehouse Flows Engineer, through consecutive meetings to discuss various approaches and possibilities to implement and define the micro-layouts, always taking into consideration the impact on efficiency and productivity improvement that the changings might have. For the purpose of this dissertation, they will only be detailed the parts of this 3D Warehouse model that will impact the simulation model. In Figure 29, firstly presented in section 2.4.2, they are identified with numbers – 1, 2, 3 & 4 – the four warehouse operations that correspond to the highlighted sections of the layout proposed for this zone of the warehouse, developed using Sketchup 3D design software and shown in Figure 30.

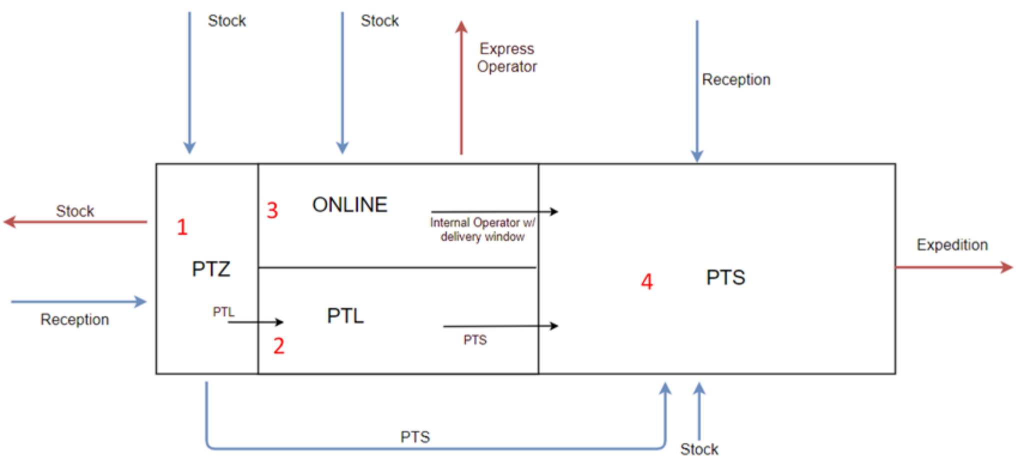


Figure 29 - Warehouse Operations Layout (To Be Scenario)

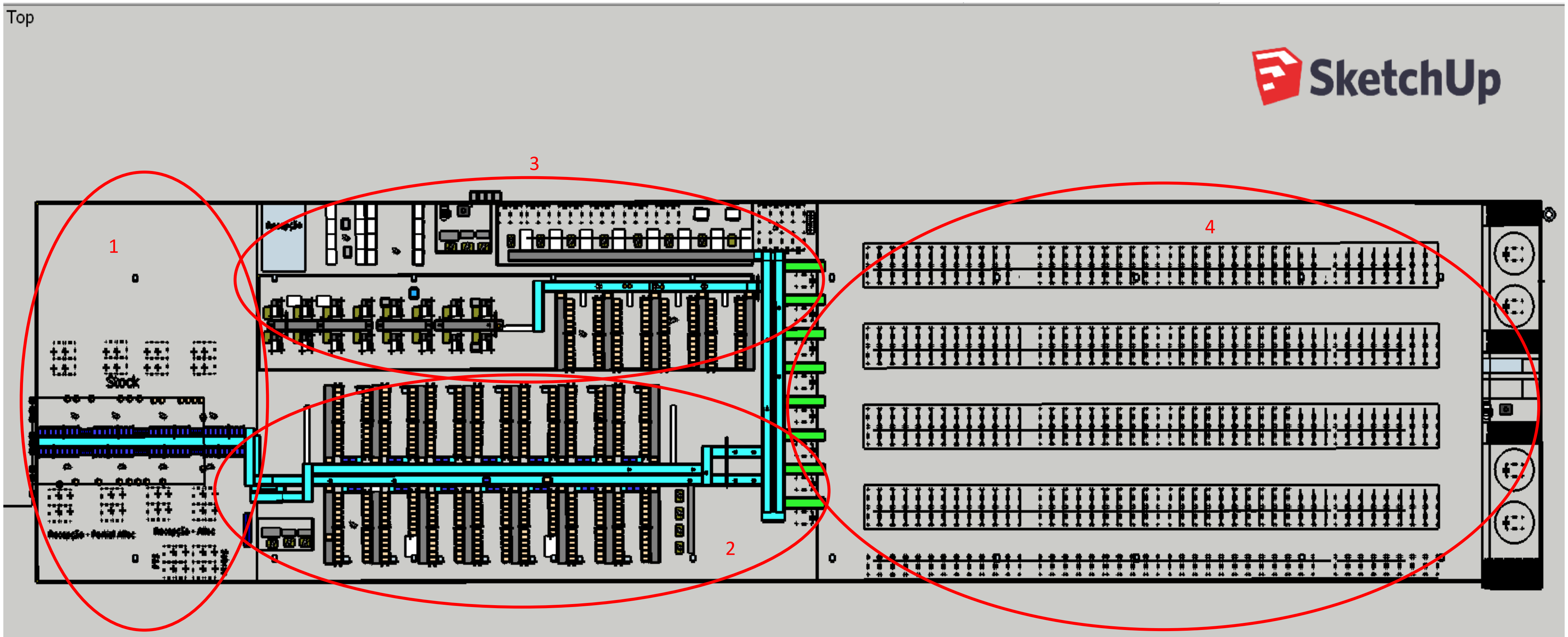


Figure 30 - Main Warehouse Operations (Sketchup Software 3D model – Top View)

4.4.1 – Operations & Micro-Layout first approach

The main objective of the present project is to reduce operational cost by improving warehouse operation flows in the central area zones PTZ, PTL, Online and PTS, with the main focus being on reducing transport inefficiencies (through a redesign of the macro-layout of these zones) and improving flows (through the insertion of the PBS flow in these areas). Through a new placement of these zones in the warehouse and its rearrangement to the new dimensioning areas along with the insertion of automation as a first step approach, in which the present dissertation is mainly focused in, the new micro-layout of these zones and the necessary capacity improvement will be considered when proposing the solution but not to the final extent of an exact solution in terms of space and number of working sectors once this requires the integration of external agents in the project such as automation suppliers (see Appendix 4).

The greatest challenge of this design model as well as one of the main purposes of the simulation is how will automation improve the warehouse efficiency. For the purpose of the present work, this will be mainly focused on reducing transport times with automation being primarily inserted to improve connections between the flows of the different areas. Considering automation systems, for transporting products, AGVs and conveyors are the ones most used (see Section 3.1.6 – Trends in Warehouse Management). Between these, it was defined that conveyors would fit best the company´s needs once they not only assure continuous flow, this is, they keep rolling and transporting the products that are stored there, whereas AGVs can only transport to a certain limit of times per trip, but also for a matter of cost, once the number of AGVs required to perform these activities would require a higher investment than in conveyors. It is then firstly added a double stage conveyor to transport full totes from the PTZ operations area to PTL sectors, each stage at the height of each PTZ stations lines of totes. When a tote is full, similarly to what is done today, where the operator pushes the tote where it remains until another operator picks it up and transports to the corresponding PTL sector, here the operator also pushes the tote but it falls into the conveyor (Figure 31). At the end of the PTZ operations area, there should be a connection to match both stages of conveyors in one so that it extends until the PTL area.

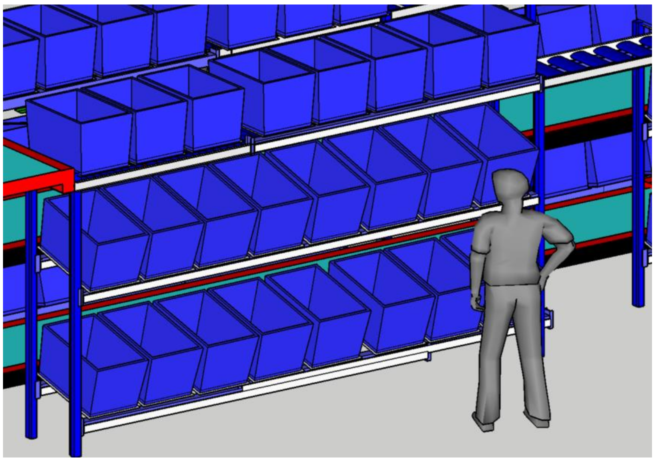


Figure 31 - PTZ sector (To Be)

One of the main objectives for the new warehouse layout is to include part of this PBS flow (not considering orders of big sized home appliances) in the PBL activities – PBS shall be done not in batch but in bulk picking, where pickers grab all the articles corresponding to all the stores that ordered that type of items and place them in the PTZ reception area. These articles follow then the same flow as the ones from PBL. This process changing implies higher amount of work in the PTZ area, once more products will arrive to this working station. There is a need, then, to extend the number of working stations and operators of this area, as well as the space required for receiving buffers. As a result, they were added 3 PTZ working stations to the model (Figure 32), resulting in a total of 8, with an additional line of totes, similar to the PTL sectors design, to support this higher work rate flow and also because the number of PTL sectors will increase **(Figure 30 – node 1)**.

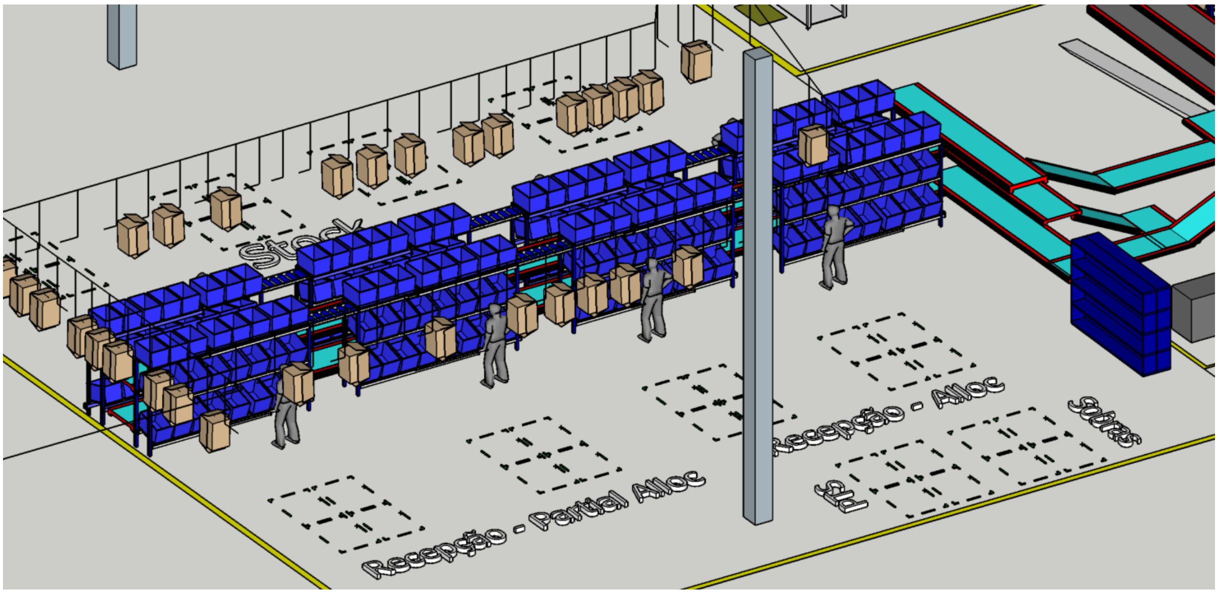


Figure 32 - PTZ operations area (To Be)

Once in the PTL area, the conveyor sorts the totes to each corresponding sector. In each sector, an operator is awaiting this tote arrival and sorts the articles to the corresponding store boxes. This central sorting conveyor that extends through all the PTL area is designed to be a carousel conveyor, so that bottlenecks are avoided – when a PTL sector is full of totes still awaiting to be sorted due to accumulated work of that sector´s employee, the conveyor does not send the tote to that sector, keeping it in the carousel until there is enough space to receive that tote. This is, as an example, directly connected with the Design Results expected to obtain in the further development of the work – how many totes, considering the flow rate at which a tote arrives to a certain sector and the average velocity/productivity at which an operator in that sector works, should a determined sector be designed to receive (Size of the PTL sector buffer). Similarly to what was made with the PTZ working stations, also the PTL sectors will have a two stage conveyor for operators to push the full boxes to, which will be displayed perpendicularly to the main central carousel. Once this central conveyor is one-staged, an electric elevation is applied to this double-staged perpendicular conveyor, so that boxes that come from the bottom level are pushed up to the top level which by its turn is placed at the same height of the central carousel. This perpendicular conveyor will feed the carousel with the full boxes which will be transported to the PTS reception area (Figure 33). It is important to mention that in the carousel conveyor there will be totes being sorted to PTL sectors as well as boxes to be transported to the PTS reception area. At the end of the carousel, there is another sorter that probabilistically sorts boxes to be checked in the Quality Control. Finally, the carousel has two parallel outputs (to avoid bottlenecks when cut-off hour occurs) with a box-closing machine.

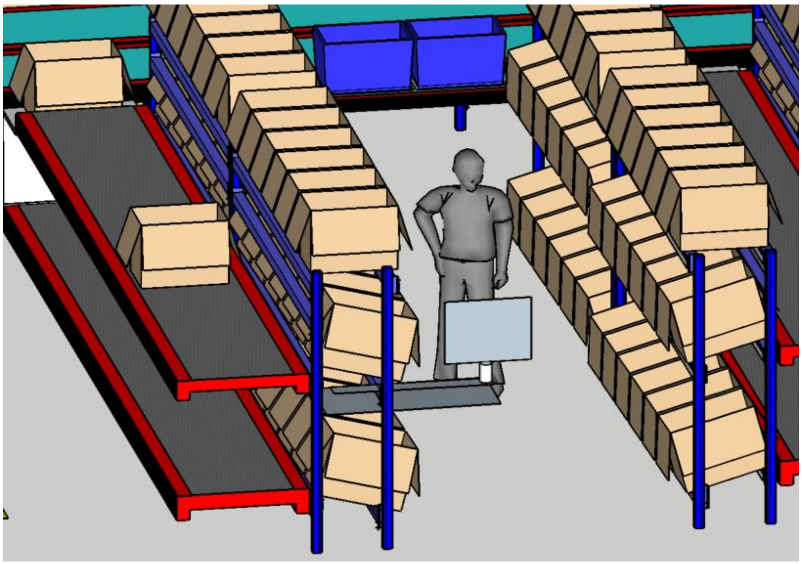


Figure 33 - PTL sector (To Be)

For the PTL sectors´ layout, the reasoning applied was similar to PTZ but instead of adding 3 PTL working stations, the purpose was to duplicate the number of working stations. This is due to the fact that, by data analysis, moreless 50% of the volumes expedited to the stores per day come from PBL flow and 50% from PBS. Once the PBS flow is being planned to be prepared in this line, it is required to duplicate the capacity of this area.

Furthermore, once Worten sales are growing, although at low rates, it is kept in mind the possible growth in sales volume through the following years what will require a higher operational productivity and capacity. Additionally it is also taken into consideration the peak demand season, which has its highest exponent on Black Friday where in the past years capacity issues have become a problem when preparing the large amount of orders for that day. By duplicating the PTL sectors, the purpose is to have each one two times, this is, two PTL PEQ sectors, two PTL MED sectors, two PTL GRA1, and so on and forth, displayed in front of one another, so that the middle corridor, that separates both sectors lines, serves as a mirror, where one side is the reflection of the other (Figure 34). By achieving this, it is possible that, in low demand seasons, only half of the sectors are working. As a result, it is reached the same number of different sectors with each one having double capacity **(Figure 30 – node 2)**. Because the number of PTL sectors will duplicate, the PTZ working stations´ micro-layout will also have to be altered so that it supports this new capacity: previously, one PTZ working stations had 6 totes in the middle level with the highest level storing empty totes to replenish the lower level ones when they were sent to the corresponding PTL sectors. Now, the PTZ working station was widened to 8 totes by level, with an additional ground level line of totes, making up the 16 totes for the 16 PTL sectors **(Figure 30 – node 2).**

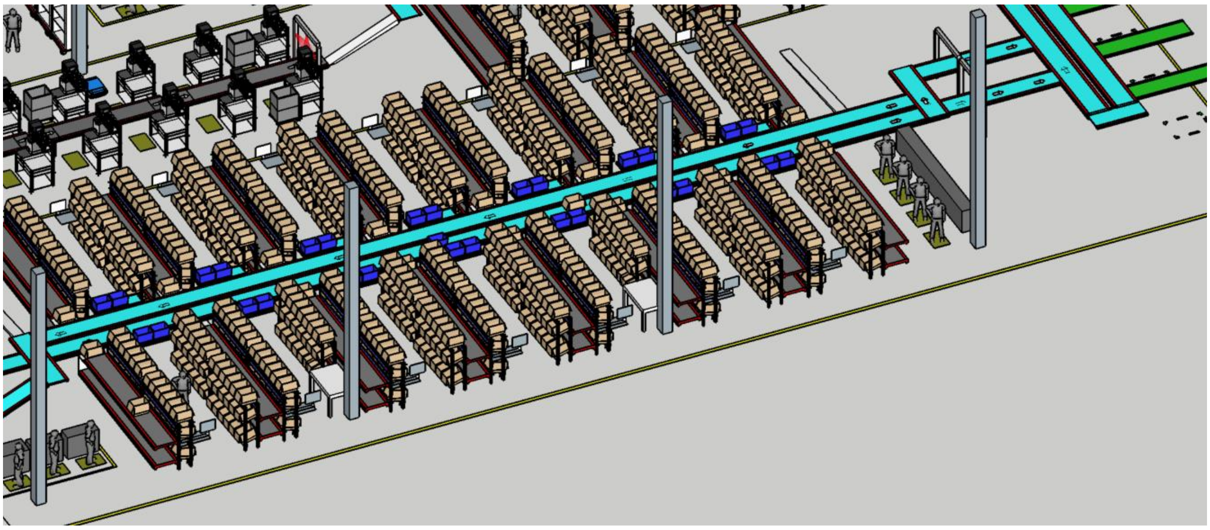


Figure 34 - PTL operations area (To Be)

Regarding the Online section, in Online PTL, the purpose is to have all the 180 stores present (currently there are roughly 120). For that, the PTL layout was adapted to the micro-layout of PBL PTL sector, keeping the 4 previous sub-sectors but now with more store boxes each. With it is also possible to achieve uniformity with all the PTL sectors in the macro-layout (both Online & PBL) having the same display. Online reception area, packing stations and Putwall do not suffer process and layout changes, with the only difference being on how they are disposed in this new area, once the flow, for now, will remain the same. Finally, the Online PTS is proposed to disappear, once now this unit is as close to PTS as PBL and the idea is to make items reach the PTS receiving zone the same way PBL closed boxes do. There is only the need of inserting a small separation area to sort articles/boxes by transportation company – internal operator or external operator – once the ones for external operator do not pass by PTS **(Figure 30 – node 3)**.

In terms of automation, in the Online flow, there is already a conveyor implemented to transport small orders from the small packing stations to the Online PTL. However, currently, these orders fall into a buffer at the end of the conveyor and one operator is responsible for sorting the articles for its different sectors. With the proposed disposal of the Online PTL sectors, it is suggested a similar reasoning to the one explained for the PBL: a main conveyor that transports and sorts the articles for its corresponding PTL sectors. This main conveyor feeds the PTS carousel. However, in this case, a carousel is not justified once the transportation objects are not totes (which require a larger buffer on sectors) but yes single packages of articles so the case of bottlenecks is not considered. The Online PTL sectors also have the perpendicular conveyors and the elevation system. One new feature is adding another conveyor to the large packing stations: currently, one operator is responsible for storing the packed products in a pallet and transport it to the Online PTS area; with the conveyor, packing operators would only have to place the articles in the conveyor which would transport them until the PTS carousel (Figure 35).

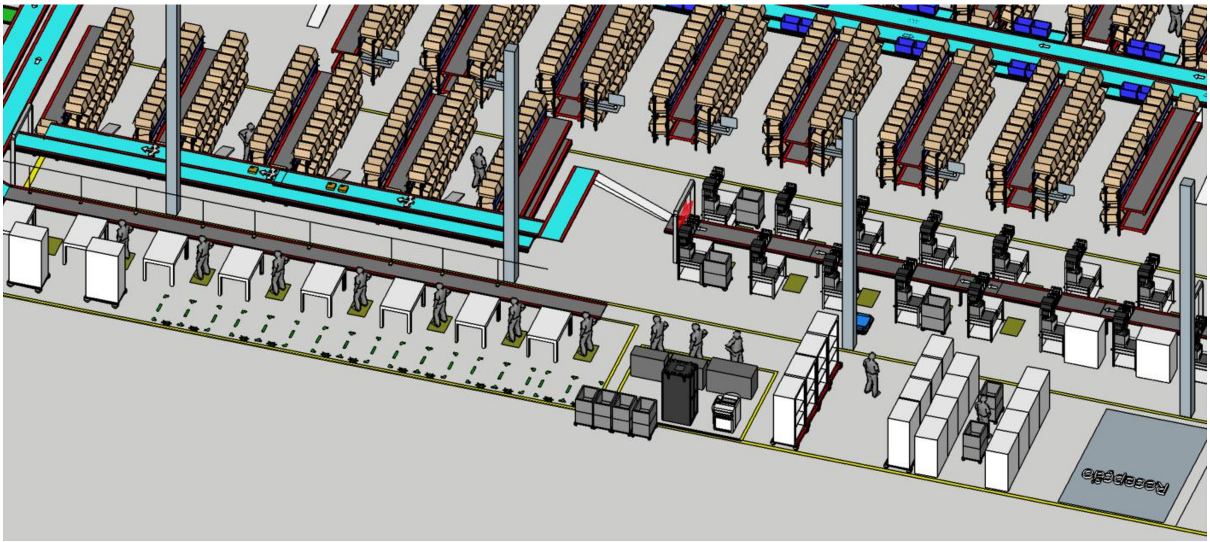


Figure 35 - Online operations area (To Be)

Both the outputs from PTL and Online sections will converge to a final carousel, displayed in parallel to the PTL carousel, whose objective is to make the connection between PBL and Online flows once both have the same output: PTS. This PTS carousel is then fed by the two closed boxes conveyors (PBL) and the large and small orders conveyors (Online). Finally, there are eight possible outputs to which this carousel will sort the transporting objects. These outputs correspond to different zones of the PTS (Figure 36). An operator is responsible from removing the objects from the conveyor output buffer and place them in a pallet. Afterwards, he/she completes his/her work by sorting by hand the articles from the pallet to the corresponding PTS pallet store location. An eight output system is preferred to the current 4 possible PTS zones, once more due to the implementation of the PBS flow in PBL which will increase flow rates and demands a better and accurate distribution fluency. In terms of micro-layout, this operations area, will not suffer, under this project purpose, any process operation changing. The flows that reach this area will not be affected other than by the way they reach it. The micro-layout of this zone will keep the same **(Figure 30 – node 4)**.

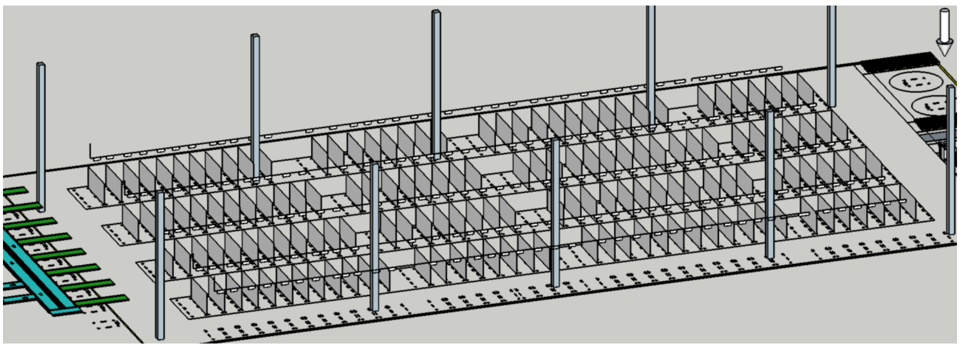


Figure 36 - PTS operations area (To Be)

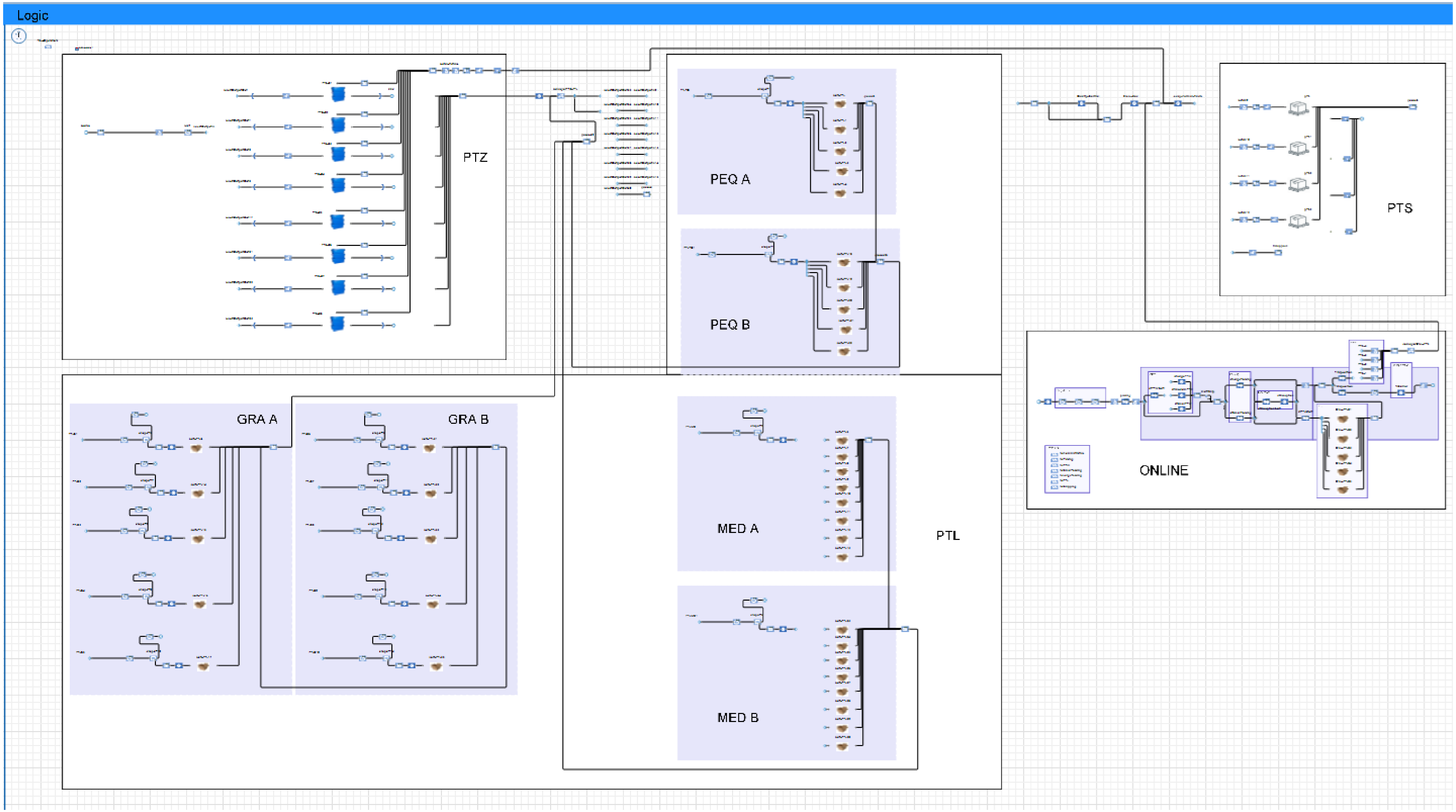


Figure 37 - To Be Simulation Model

4.4.2 – Model Representation

After the presentation of a proposed model using 3D software, it is proceeded to the representation of this proposal in a simulation model, shown in Figure 37. The reasoning basis and simulation tools used in the To Be model will be similar to the ones explained for the Scenario As Is (see Section 4.3.2), however with additional working stations, different micro-layout of each working station with higher capacities, the integration of the PBS flow and automation systems. In Figure 38 it is shown the model representation of the PTL carousel conveyor.

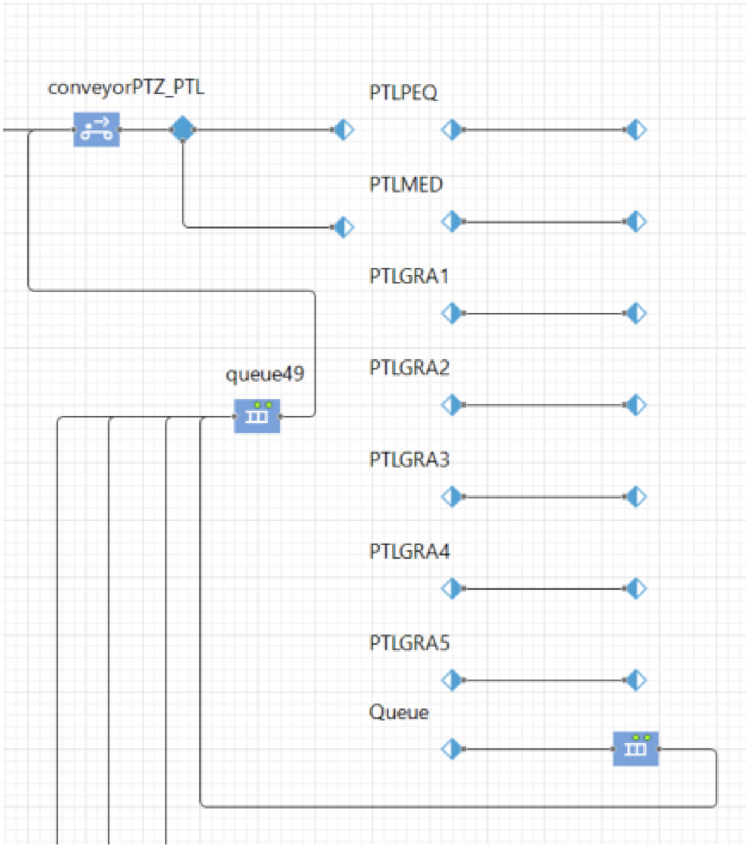


Figure 38 - PTL conveyor

One other important assumption taken during the development of the Scenario To Be model, accounts for the PTZ and PTL working stations. PTZ working stations will be larger due to more existing PTL sectors. Also, PTL sectors will include more store boxes. However, studies such as which additional stores will be placed in which sectors are still being carried out and depend on several conjugations of factors, such as automation requirements, project budgets or number of stores that are going to open. Once again, the objective of the simulation model is comparing both scenarios by evaluating the overall performance of the system and these kinds of specifications will not influence the results comparison but yes the performance of one system by itself. What was done in regard of this issue, was adding the demanded number of working stations to the model but with the operations inside these working stations being the same of the ones represented in the Scenario As Is. This is to say that, the eight PTZ working stations and the 16 PTL sectors were modelled but the operations inside these agents (PTZ and PTL) were not changed. As the simulation results presented in future sections prove, with the insertion of PBS flow and automation in the system, there is already a considerable improvement in the overall performance of the system, which is expected to be exponentiated with improvements in these working stations´ operations after having defined the parameters that are missing at the date of this Dissertation Project.

4.4.3 – Definition of the Results

The results proposed to achieve with the scenario To Be are already explained in Section 4.3.2.

4.4.4 – Metrics Parametrization

Regarding the metrics parametrization of the Scenario To Be, these resemble to most of the ones explained in Section 4.3.4 regarding operational fields that can not be changed such as operator´s input productivities (how much time it takes for an operator to place one article in a box; once the operators are the same in both scenarios, their input productivities do not change) or sizes of pallets/totes. These are inputs directly measured on track that shall not be different from one scenario to the other, once the aim is to study how would the overall system perform under the assumptions made. However, there are metrics that are forced to be changed and other assumptions have been taken into consideration for those measures. These assumptions rely mostly on the parts of the simulation that are being tested, meaning automation conveyors. Technical knowledge on how these systems perform and which requirements they need to achieve the performance proposed is on Automation Suppliers. With this, it is meant transfer tables, sorters, connections between conveyors, conveyor speed, conveyor size, delays, possible breakdowns or bottlenecks management – all of these will have its impact, even if in low variabilities, in one simulation model. In order to overcome this issue, and because this specific simulation does not require such a type of detail but yes the overall performance of all the operations, the already implemented conveyor in the small packing stations of the Online operations area of the warehouse was taken as the example for this study, with its parameters having been measured on track and used as inputs for the simulation model. Posteriorly, during the development of the company´s project, contacts with automation suppliers will be carried out and these values, with a more exact precision, will be presented by them.

4.4.5 – Adjustments & Validation

By multiple runs of the model, it was necessary to correct mistakes and observe if the model is actually working the way it is meant to work – if the functions programmed are correctly working as well as the variables and parameters registered and altered through time and the results being updated. The necessary adjustments were made to the model until being validated.

Chapter 5 – Analysis of Results

In this chapter, the simulation results will be presented and analysed. An approach of how input metrics might be changed without the need of re-designing the model will be detailed as well as the Online AnyLogic tool utility for Warehouse managers.

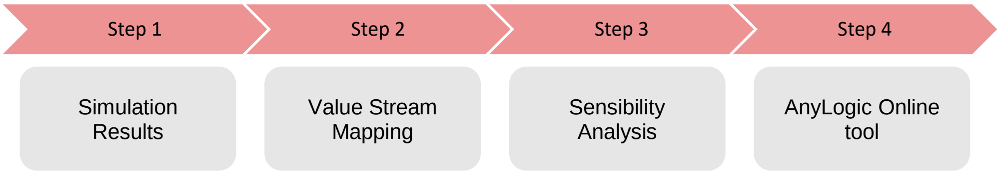


Figure 39 - Methodology for Analysis of Results

In a first approach, results from both simulation models (Scenario As Is & Scenario To Be) will be presented, compared and discussed. Afterwards, Value Stream Maps (VSM) of both scenarios are developed, presented and compared, followed by a Sensibility Analysis of the Outputs of both models when the input data is modified, more specifically, the month data being used in the simulation. Finally, an approach on how the AnyLogic Online software tool is useful for warehouse managers is detailed.

5.1 – Simulation Run Experiments & Warm-up Period

Due to the excessive amount of information, parameters, tables, variables, functions, plots and results programmed on the Simulation Model, the software became overcharged and it was necessary to resort to a High-Performance (HP) computer to run the experiments. The company made its HP computer – with a more powerful CPU (Central Processing Unit) and higher Memory than traditional computers - available for this present work, in which the experiments´ runs were made.

For the purpose of this work, it was not necessary to define a warm-up period, common in most simulation models. As Mahajan and Ingalls (2004) explained, the purpose of one simulation model is to estimate long run characteristics of one system´s behaviour and almost everytime simulation models start idle and empty, which differs from the steady state condition that are aimed to be tested. In regard to this, one simulation model normally takes time to reach that steady state, and it is this time, considered a transient state, that is referred as the simulation´s warm-up period. However, holding to what these authors mentioned, this occurs in almost all simulation models. The simulation model being studied in this present work, remains in those exceptions that do not require warm-up period. This is due to the fact that there is a close line timing everyday in these operations, which signifies that at the end of each day, the system comes back to state zero. Following this reasoning, everyday the system starts from state zero – with all the working stations empty and with work starting with the arrival of the trucks to the reception area of the warehouse, it is concluded that that warm-up period until steady state is required everyday – once the arrival rates of articles to the areas are scheduled, there is no need of defining a warm-up period for this specific simulation model.

5.2 – Simulation Results

As mentioned before, in this section the results obtained from the two first run experiments, from scenarios As Is and To Be are presented. An analysis and comparison of both scenarios results is also detailed.

5.2.1 – Scenario As Is

Regarding the operations close line time, the plot presented in Figure 40 – in which the vertical axis represents the hours and the horizontal axis the simulation time - was obtained for the Scenario As Is. Values vary a lot throughout the simulation time – represented by a standard deviation of 0,53 – with a peak (3.42 hours) recorded in the middle of the month which accounts for the stores supply preparation for Black Friday. An average of 1.69 hours for closing the operations line is registered.

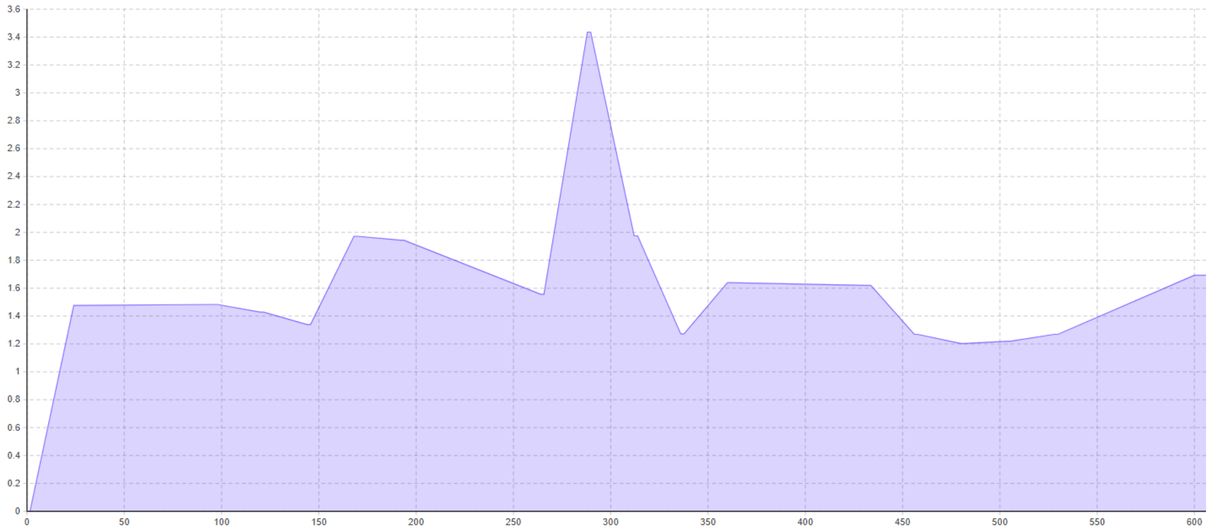


Figure 40 - Close Line Time (Average: 1.69 hours; Standard Deviation: 0,53; Vertical axis: hours; Horizontal axis: simulation time)

On behalf of the occupation rate of PTL sectors, for a matter of measuring output results, instead of assigning one resource as an operator for each of the sectors and evaluate its occupation rate, as it was done for the transport operators, it was measured from the total working time for these operations shift, how much time was spent in sorting the products. With this, it is achieved the occupation rate of one full-working operator in each of these sectors. In the following presented histograms, vertical axis represent percentage of total time and horizontal axis represent number of employees.

From these PTL output results, it was obtained an average of 57% occupation rate for the PTL PEQ sector and 51% for MED sector (Figures 41 & 42, respectively). This means that only 57% and 51% of the total working time, were the PEQ and MED sector operators actually working, respectively, with the remaining time being idle (the left column of each of these plots represents zero operators working or no work to be done in the sector and the right column the opposite: the operator is working or has work to do).

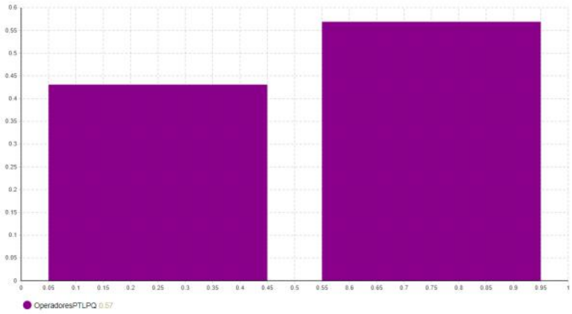


Figure 41 - PTL PEQ Operators Occupation

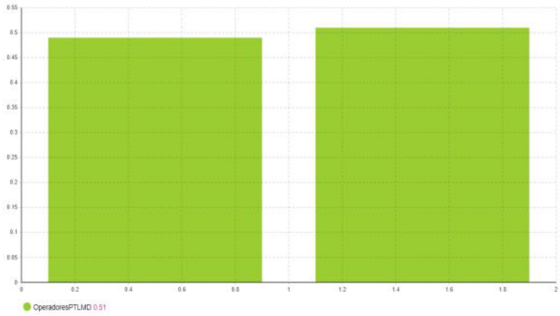


Figure 42 - PTL MED Operators Occupation

For the GRA sectors, the results obtained meet the expectations as GRA1 sector has the highest occupation rate in comparison with the remaining sectors once it is in that sector that the stores that receive the highest sales volumes are present – 74% occupation rate of the PTL GRA1 operator represented in Figure 43. Sectors GRA2, GRA3 and GRA4 registered occupation rates of 67%, 67% and 61% respectively, as represented in Figures 44, 45 and 46. Finally, also as expected, GRA5 sector has the lowest occupation rate – 10% (Figure 47). In regard of this sector, as operations occur in reality at the warehouse, there is no fixed employee responsible for this sector, with its needs being satisfied in idle times of operators from the remaining sectors. In other words, when for example the operator from sector GRA3 finished sorting all the products from the totes left in this sector from transport operators, and if there is work to be done in GRA5 sector, instead of being idle in sector GRA3 waiting from work to get there, this operator is responsible for moving to sector GRA5 and do the work that was left there. However, for a purpose of testing this possibility and to assure that this is the best option for the operational productivity, the simulation was run as if there was one operator responsible for this GRA5 sector. The strategy followed by the company is proved and validated by this simulation run.

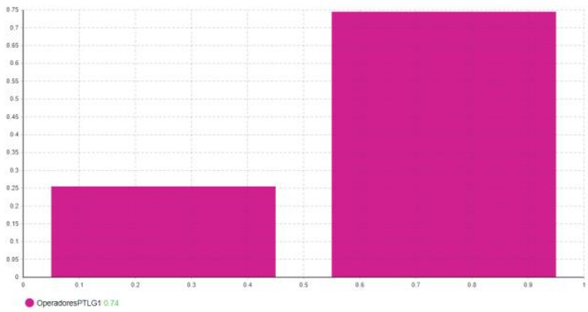


Figure 43 - PTL GRA1 Operators Occupation

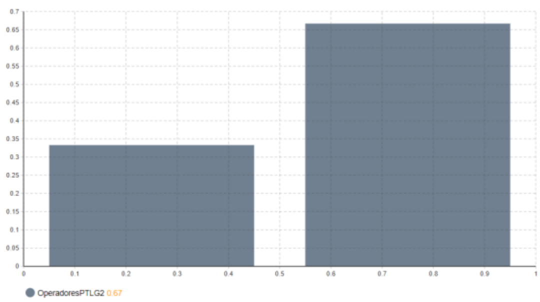


Figure 44 - PTL GRA2 Operators Occupation

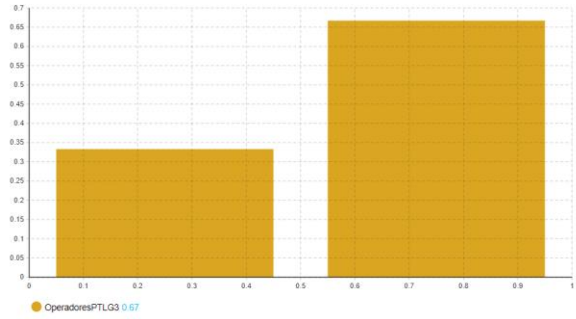


Figure 45 - PTL GRA3 Operators Occupation

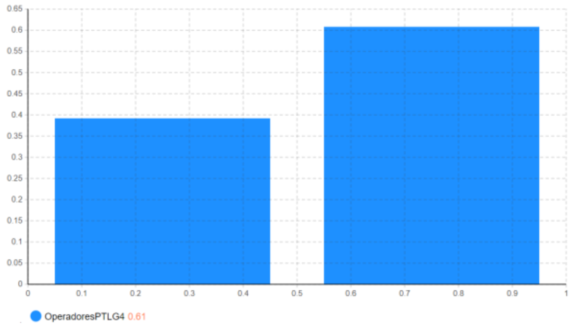


Figure 46 - PTL GRA4 Operators Occupation

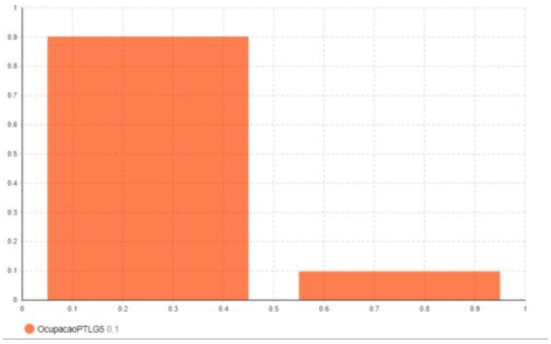


Figure 47 - PTL GRA5 Operators Occupation

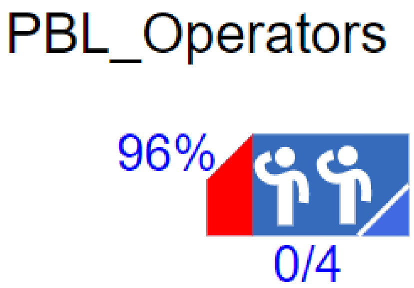


Figure 48 – Transport Operators Occupation

In Figure 48 it is represented the simulation output of the PBL Transport Operators' occupation rate – the operators that are responsible from transporting the totes from PTZ operations area to PTL sectors and from PTL sector to the PTS receiving area – where a 96% occupation rate was obtained. From the conjugation and comparison of the occupation rates already obtained – PTL sectors and transport operators – it can already be detected a discrepancy between values: while PTL sectors operators occupation rates are above considerable values, transport operators occupation rates are almost at its full capacity which is a first indicator that the work is accumulated in this operation what can be considered close to an operation bottleneck that might be interdependent – work is overcharged in transport operators that do not have the capacity of satisfying its subsequent feeding operations. In other words, PTL sectors operators lack of occupation might be related with the inability of transport operators of placing the totes/boxes in the correct points at the right time.

In a macro-perspective of evaluating the operation zones on its whole (by activity and not by operator), in the As Is scenario, Figures 49 and 50 were developed to approach PTZ and PTL operations areas. From Figure 48, it is concluded that there was an average of 2.54 operators working from the total of 5 from the total simulation time. However, considering these operations, it is not expected that the automation systems will improve much this occupation rate once it is only from this operation forward that these systems will be implemented. The input flow of this area is uniquely related with the reception schedules of trucks/suppliers and its unload operations that do not belong to the scope of this present work. The same reasoning is applied to PTL operations area, where there was an average of 3.27 operators working out of the total of 7 operators from the total shift working time. Roughly 14% of the time there was no operator working, 12% there was only one of the 7 working, 6% two and so on and forth. The highest occupation values are achieved for 5 and 4 (33% and 26% of the total working time, respectively) PTL operators working at the same time.

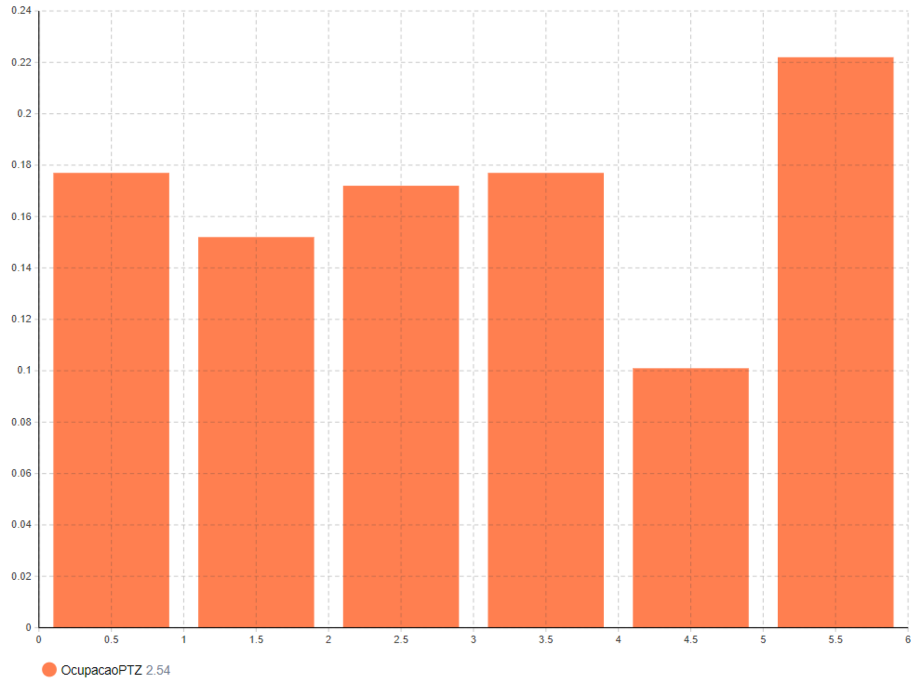


Figure 49 - PTZ Operators Occupation

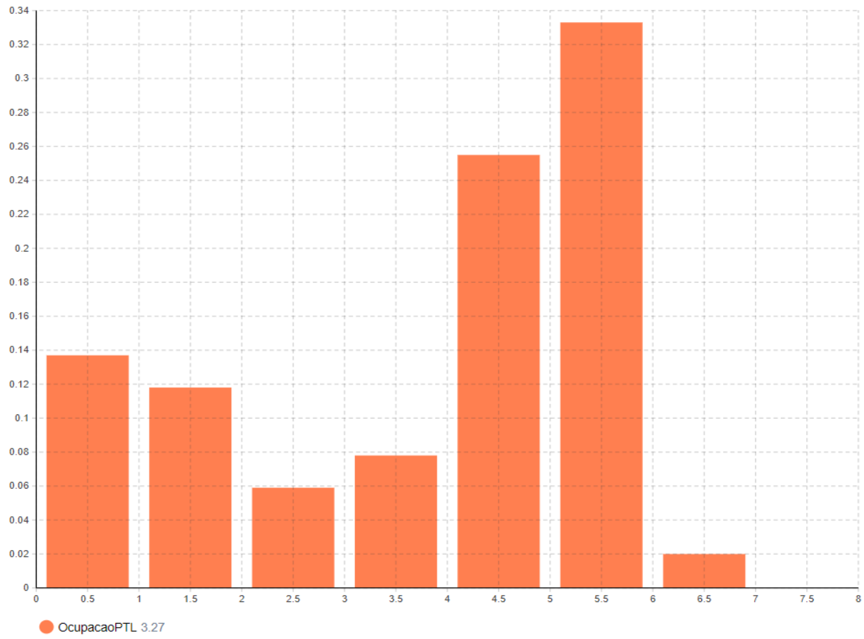


Figure 50 – PTL Operators Occupation

5.2.2 – Scenario To Be

After the insertion of the PBS flow in the model of the Scenario To Be, the operations close line time already shows an improvement of inserting automation systems. The values are much more constant – proved by standard deviation of 0,15 obtained when compared to the 0,53 standard deviation of the previous scenario – which is related to the assurance of a constant flow rate from conveyors: products no longer await the availability of an operator to be transported; the conveyor already transports them to PTS. Additionally, an average of 1.14 hours for closing the operations line contrasts with the previous 1.69 hours from the Scenario As Is, showing a reduction of 32.6% of time (Figure 51).

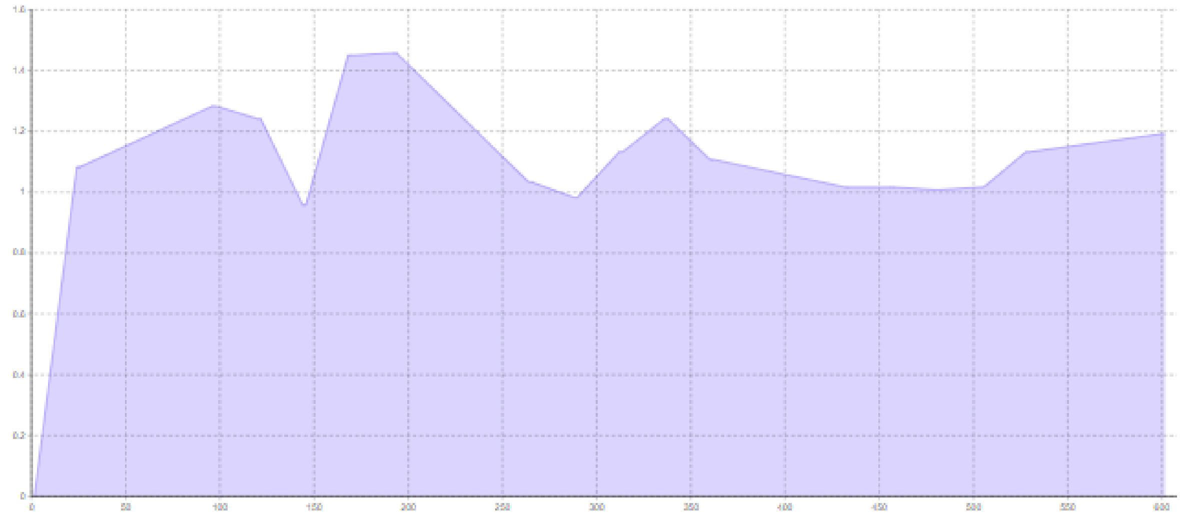


Figure 51 - Close Line Time (Average: 1.14 hours; Standard Deviation: 0,15; Vertical axis: hours; Horizontal axis: simulation time)

From the run experiment of the To Be simulation model, the results obtained seem to prove the theory that the automation systems inserted in the flows and operations being studied improve the overall efficiency and productivity of the corresponding zones. For the PTL sectors, once these were duplicated, the occupation rates were calculated taking into account both sectors of each type. This is to say that, taking as example the PTL PEQ output histogram (Figure 52), the 80% occupation rate obtained takes into account both sectors – 80% occupation rate of the two operators of the PTL PEQ A and PTL PEQ B sectors. The same reasoning is applied to the following sectors. Regarding PTL MED sectors, there was obtained a 91% occupation rate of the operators (Figure 53).

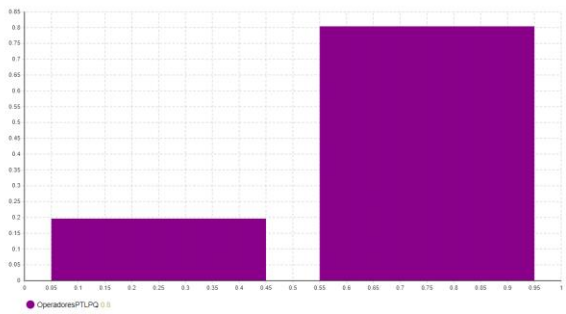


Figure 52 - PTL PEQ Operators Occupation

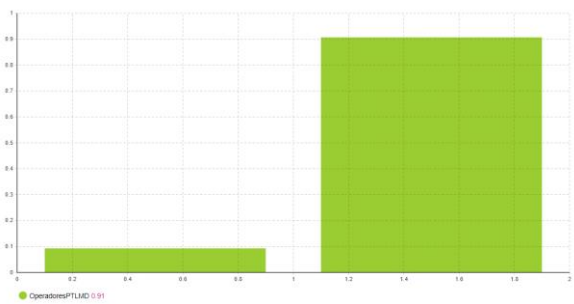


Figure 53 - PTL MED Operators Occupation

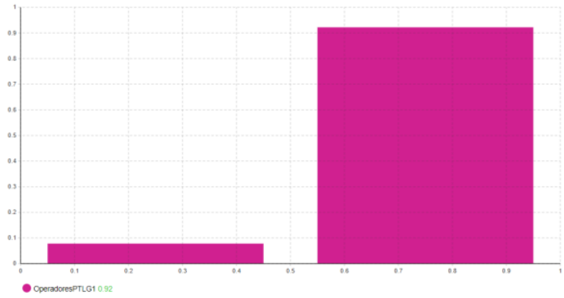


Figure 54 - PTL GRA1 Operators Occupation

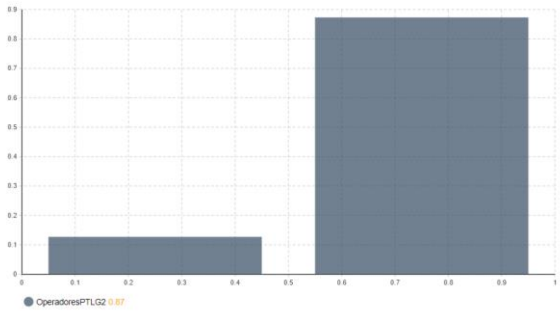


Figure 55 - PTL GRA2 Operators Occupation

In PTL GRA1 sectors, it was such as in the As Is scenario, obtained the highest occupation rate of the PTL sectors – 92% (Figure 54). This suggests that possibly it should be analysed the stores distribution in the different GRA sectors, once these results suggest that the work is not distributed evenly by the PTL sectors. The occupation rate of PTL GRA2 sectors was of 87%, GRA3 84% and GRA4 85% (Figures 55, 56 and 57, respectively). Once again, GRA5 had the lowest occupation rate – 25% (Figure 58). All the sectors should have a similar occupation rate when work is evenly distributed by them which is not the case currently as the results prove.

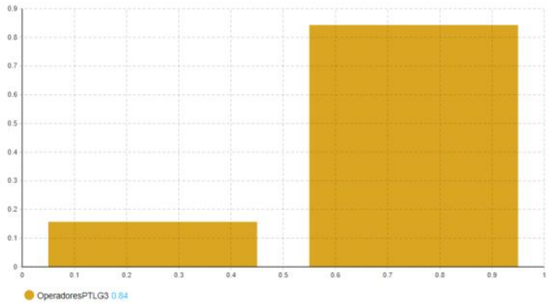


Figure 56 - PTL GRA3 Operators Occupation

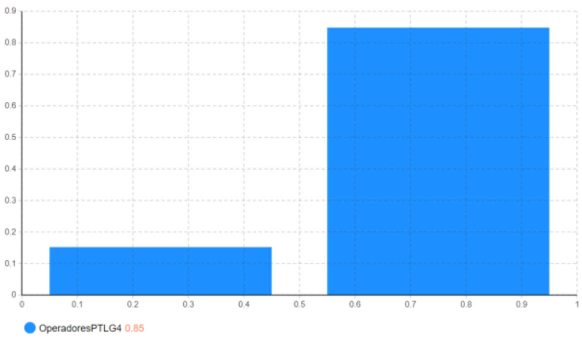


Figure 57 - PTL GRA4 Operators Occupation

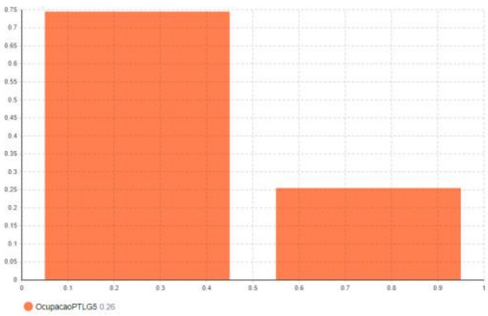


Figure 58 - PTL GRA5 Operators Occupation

Regarding the overall occupation rates of the operators of PTZ and PTL operations area, they were obtained the results presented in Figures 59 and 60, respectively. In the To Be scenario, apart from the fact that they were added three working stations, in percentage the occupation rate was not much improved, once the automated systems do not affect the occupation rate of these zone operators. As said before, the input flow of PTZ comes from reception and suppliers arriving schedules. The value of an average of 4.47 employees working out of the total of eight (55%) - versus the 2.54 out of five obtained in the As Is scenario (50%) - is related with the insertion of the PBS flow in this operation. Once PBS represents 50% and PBL the other 50% of input work, the flow rate was duplicated whereas the working stations were not. This is believed to explain the short improvement of the occupation rate of PTZ operations area.

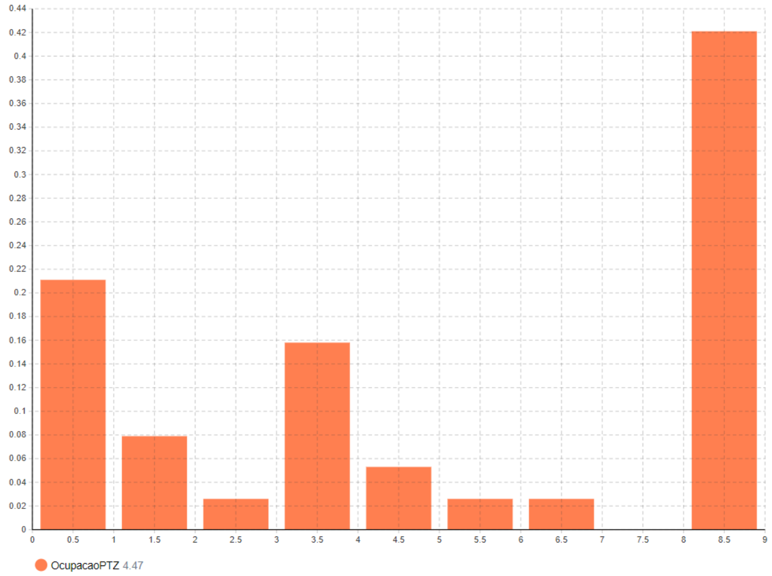


Figure 59 – PTZ Operators Occupation

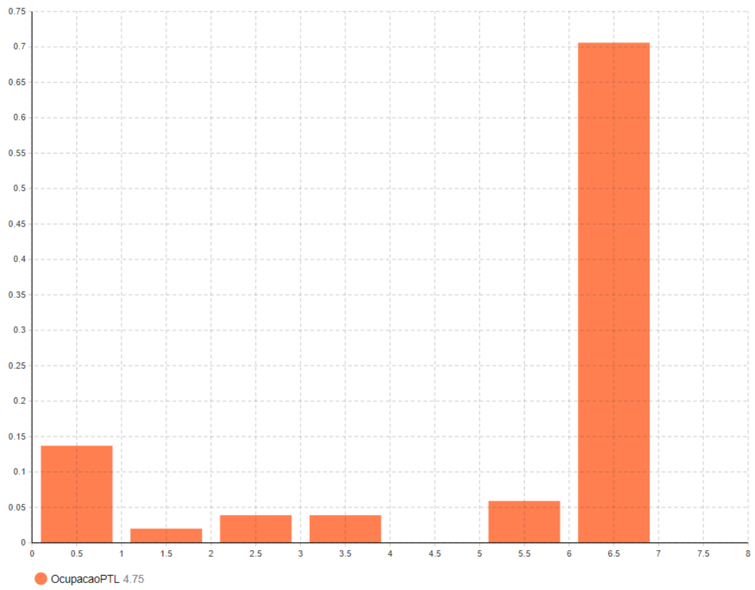


Figure 60 - PTL Operators Occupation

However, PTL operators occupation rates were clearly improved on the overall. From the previous average occupation of 3.27 employees (46%) the To Be scenario shows an improvement into 4.75 (68%), representing a gain of 22% in the operators occupation rate on its overall. This is related to having the products available in each sector shortly after they have been sorted in the PTZ operations area, with the time these articles waited for a transport operator to be available to place them in the corresponding PTL sectors no longer being lost.

5.2 – Value Stream Mapping

According to Carmigani, G. (2017), Value Stream Mapping is one the most powerful tools to map processes as well as identify and eliminate its non-value added steps (Figure 61). Using Wang et al. (2011) approach on how VSMs are useful to analyse engineering processes, by providing the value added ratio of an overall process (Time of value added activities under the total process time), it is possible to compare the improvement in operational efficiency that the To Be scenario presents in relation to the As Is scenario by reducing the time spent in non-value added steps of the process, meaning in this specific case, transportation, and, by means of this, concluding the Macro-layout Operational Validation of the automation project.

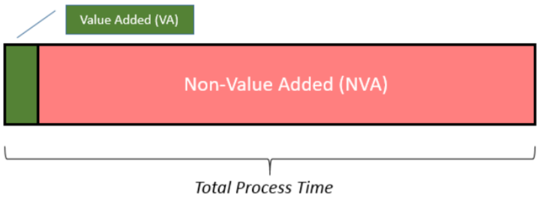


Figure 61 - Value Added vs Non-Value Added activities of a process

For the purpose of this present work, the focus on reducing non-value added activities is on decreasing the time spent in transporting activities, by substituting people for automated conveyors. At first sight, it is possible to conclude that an automated conveyor assures a continuous flow of transporting objects whereas a person is limited to a discrete flow. This is equivalent to say that while a conveyor is always rolling and there is no idle transporting object time – once a tote or a box is ready to be sent to its following destination, it is pushed to the conveyor that transports it immediately to its correct place – a person cannot guarantee that continuous flow – once a tote or a box is ready to be sent to its following destination, it has to wait for an operator availability to transport it and thus, that operator is limited to transporting X totes/boxes at a time. The same aplies to AGV automation transporting systems – although the wait time of the object for the availability of this transporting method could be reduced with the increase in the amount of AGVs, it is yet always limited to a certain capacity of the AGV. This had an important impact in the company´s decision for the conveyors on behalf of AGVs.

In the system being studied the non-value added activities are split in two – idleness (wait time for the transporting resource availability) and the transporting time itself. Considering the value stream maps of each of these activities, these have many inter-dependent variables associated to the iddle time that are external to the system itself. Taking as example one SKU that arrives to the PTZ operations area, its cycle time may be short (sorting time) but its idleness may be too varied – once the SKU is placed in the corresponding tote it waits for that tote to be full and afterwards waits until the tranporting resource is available. In order for that tote to be full, this depends on the orders of that corresponding PTL sector stores as well as the arrival time of the articles ordered by the stores of that sector arrive to the PTZ operations area (they may come from different suppliers that may have different inbound scheduled arrival times). So by mapping these activities value-streams, these would be too influenced by uncontrolled external factors and its results would not provide the best value for this present work. As a result, and in order to observe the impact of the implentation of automation systems in the model, it was taken as unit of measure not the object but the time. With this it is meant to say that from the total working hours of one working day, they were measured the hours of that day spent in transporting objects, which represents non-value added time. From the simulation experiment of the scenario As Is, it was outputed that an average of 19.78% of the total working hours of one day were spent in transporting objects (Figure 62).

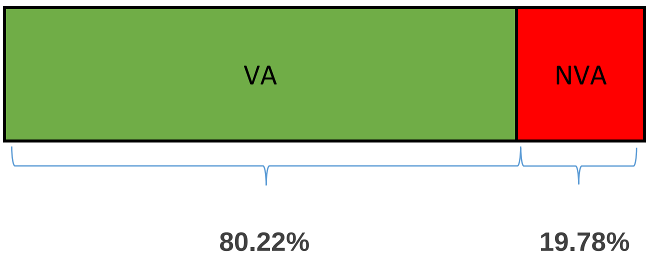


Figure 62 - Scenario As Is: VA vs NVA

Through the implementation of automated conveyors, the scenario To Be provided the results shown in Figure 63 – from the total working hours of one day an average of 8.97% of that time was spent in transporting objects.

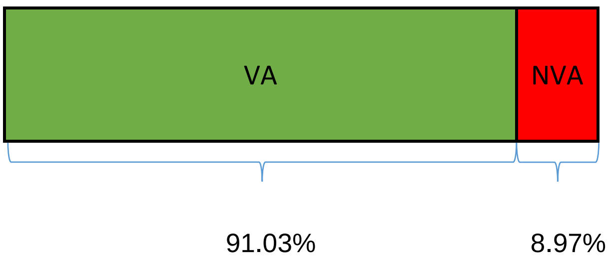


Figure 63 - Scenario To Be: VA vs NVA

This results in a decrease of over 10% of the total working time that is currently spent in object transportations. However, it is necessary to refer that the increase of over 10% in value-added activities must be accompanied by a higher working flow rate which in fact occurs in the To Be scenario with the inclusion of the PBS flow in the operations being analysed .From Table 7, it is possible to conclude that from the total working time of one day, there was a reduction of over 50% of the non-value added time. This is, from the total working time paid by the company (the sum of this corresponding areas´ operators shift schedules), the number of hours that the workers were doing transportation activities is highly reduced with the implementation of conveyors. In a reverse reasoning, the value added time is increased (it is still important to refer that this value added time may still have idle times included that do not actually create value for the company but that are required to be spent such as breaks). The number of operators is also reduced: the 4 transport operators are no longer necessary as this work is done by an automated system and the reduction on PBS personnel is significant – currently there are 12 PBS operators responsible for picking whereas with PBS flow being prepared in the PTL sectors, which are 7, there is a reduction of an additional 5 operators, with the picking being done by the current PBL employees.

Table 7 - VSM comparison: *As Is vs To Be*

Results	Scenario As Is	Scenario To Be	% Change
Non-value Added Time	26.32 hours	11.93 hours	-53.7%
Value Added Time	106.68 hours	121.07 hours	+13.5%
Number of Operators	31	22	-29%
Operators occupancy rate	48.1%	55.7%	+7.7%

5.3 – Sensitivity Analysis

A sensitivity analysis aims to study the impact of input uncertainties on the outputs variability. In this case study, the input agents generated to the simulation model are added according to an extracted table from internal database, which has the record of the time of arrival of the agents to the zone of the warehouse being studied (see Section 4.2.2). Thus, the number of incoming agents is also influenced by the data contained in this table. With this, it must be taken into consideration the different demand variabilities mentioned in Section 4.2.1. Considering one year as a cycle time of the operational demand, when there are three different demand variabilities – low (February to May), medium (June to August) and high (September to January) – using as a simulation input uniquely the high demand season as experiment with the intent of designing a warehouse operation zone may be risky. Furthermore, using only the month of November, which is the month with highest operational demand, may lead to disruptive results in terms of occupation rates. This is, when investing in equipments such as automation systems, these should be designed to perform at the maximum capacity required by the operations at its peaks. But, at the same time, it should be considered that if, for example, the high demand season, accounts for a 50% higher operational demand than the medium demand season and 80% higher than the low demand season, it might result on excessive investment that will be only be used half of the year. This decision of whether it is profitable to invest in these systems if that is the case belongs to the board of directors of the company but it is part of this project work to provide them with the required information for taking that decision. It is for that reason that a sensitivity analysis was developed, in order to study the impact that the operational demand variability used as input to the model has in the overall output results.

They were ran two additional experiments in the To Be simulation model using as inputs the data referent to the months of February and July, correspondent to a month of low and medium demand season, respectively. The outputs generated by these experiments are then compared with the one referent to the month of November through a sensitivity analysis. Table 8 was developed to summarize the results obtained.

Table 8 - Conveyor Input flow rates

	Conveyor Input flow rate (Average/minute)		
Month	Totes flow rate PTZ-PTL	Boxes flow rate PTL-PTS	TOTAL
November	1.99	2.18	4.16
July	1.30	1.35	2.65
February	0.90	0.85	1.75

By analysing Table 8, it can easily be concluded that there is a significant reduction on the input flow of objects to the conveyor. From November to July, there is a decrease of roughly 36% of the occupation rate of the conveyor and from November to February that decrease exceeds 57% - in Figure 64 this decrease becomes even more evident. These values might rise the doubt of whether such an investment is profitable and reliable.

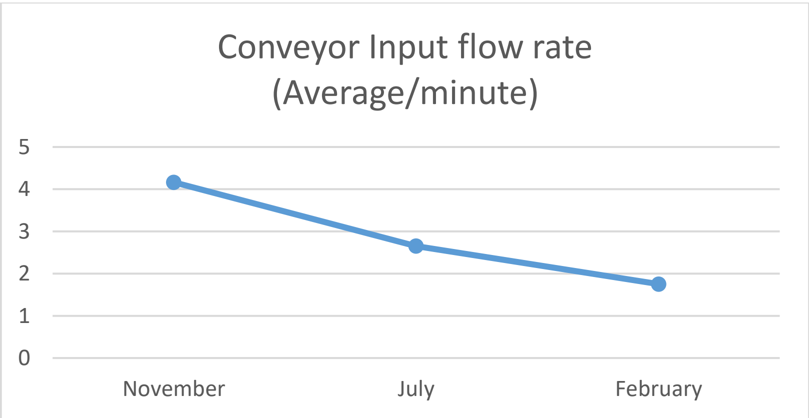


Figure 64 - Conveyor Input flow rate (plot)

However, this possibility has already been taken into account when designing the new macro-layout of these four zones. It is expected that the automation system to be inserted in the PTL operations area will represent the greatest part of the expense of the overall project, due to the large dimensions in terms of conveyor meters required, to the numerous sorters required, perpendicular conveyors, boxes elevators, among others. Once the fixed costs cannot be managed, the variable costs however, can. With variable costs it is meant number of required operators and energy and maintenance costs. By serving as a mirror to each side operation sectors – each side has the same number of sectors corresponding to one another, this is, PEQ sector of one side corresponds to the PEQ sector of the opposite side, serving this duplication only to deal with the excess of capacity related with the insertion of the PBS flow in these operation areas – when low demand seasons occur, it is possible to have only one side ot the conveyor working. Furthermore, there are several external variables that although they do not have a direct impact on these occupation rate values, they do play an important indirect role on the viability of this project: it must not be forgotten that by inserting this automation system and expanding the capacity of this operation zone, it is possible to bulk pick PBS flow instead of batch pick as it is currently done. This, apart from improving directly productivity, reducing picking times and distances and lowering personnel costs suggests that only with a very high efficient transportation system would this intent result. Finally, although there is an evident decrease in occupation percentage, taking into account the lowest value (1.73 objects per minute) by itself, it is definitely still a reasonable input flow for a conveyor.

5.4 – AnyLogic Online Tool

A simulation model is oftenly designed by a single person or a limited group of people, that have the technical required knowledge of the software system. When one designs a model, it should be taken into consideration that other people not involved in the creation of the model may require access and understanding of how the model represents the real operations and flows. The outputs generated by the simulation will be used in decision-making of various management areas of the company, that range from warehouse managers, on how these changes affect the operations inside the warehouse, to the board of directors on how the improvements expected to achieve outlie the cost-investment in automation systems. Additionally, it shall be considered the future using of the model in order to take different experiments and evaluate how they impact the warehouse flows and operations efficiency, by varying the inputs that are generated into the model.

Regarding this, AnyLogic software provides a very useful tool: the AnyLogic cloud. With free access to every user that creates an account, the user that developed one model is allowed to share the model with other users by providing access to them. It allows other users to view, change inputs and run the model in unlimited experiments. The functionality of the model is preserved by not allowing other users to change the model itself but only the input parameters that the model creator allowed to be changed.

It was bearing this in mind that the whole model was developed and designed, by not assigning variable parameters (such as trip-times, capacities, usage percentages, volumes, among others) directly to specific blocks in which these values are required, but yet providing these values as inputs that might be changed when running an experiment. Taking as example the time it takes, in the PTL operations area, to close one PTL box, instead of assigning to the delay block that represents this time 10 seconds, it is associated the parameter “close time box” along with a slider that ranges from 0 to 100 seconds and, when one runs an experiment of the model, is allowed to range this close time box between 0 and 100 seconds and evaluate the impact that this time has on the overall performance of the system model. In this case, for example, if it is identified that by using a close box machine that reduces this time from 10 seconds to 2 seconds the overall performance of the system improves X%, then it might be considered investing in these close box machines.

With this, warehouse managers can test different scenarios by varying the inputs with the aim of identifying possible improvement opportunities and evaluate its results. It does not require a software installation or any technical knowledge on simulation and modelling and its simple and safe use as well as its intuitive understanding remarks it as a very powerful and useful tool.

Chapter 6 –Conclusions & Future work

In this Chapter it is made an overall analysis of this work, by not only evaluating the KPIs previously defined and if the results obtained match the initial defined purposes of this Dissertation but also presenting the future steps to be taken in order to give continuity to the work produced.

6.1 – Conclusions of the work

In Chapter 5 the results from both scenarios of the simulation were presented, analysed and compared. After the definition and representation of a new micro-layout proposal for the areas being studied using 3D drawing software tools, as expected, the improvement from As Is scenario to the To Be scenario was confirmed, not only through direct analysis and reading of the outputs generated but also by a more detailed analysis with the aid of value stream maps of the operations where the non-value added time of the process was reduced and the value-added improved, resulting in a more efficient and productive overall process. The sensitivity analysis subsequently performed allows to evaluate the impact of the automation systems in the cycle year, which will aid decision-makers to evaluate the viability and profitability of the solution presented when compared to the cost investment inherent to it. Additionally, the access to the AnyLogic cloud where the model can be tested in various experiments by varying the inputs to the model adds value to the simulation project and is a useful tool that is made available for these decision makers. It is believed that a working basis for further improvement in the warehouse operations was solidly created, namely PTS and Online operations. It is also concluded that the objectives of the work initially defined were achieved as well as KPIs show the operational improvement and subsequent cost reduction of the overall processes through a reduction of the close line time, maximization of the operators occupation rates and reduction in number of employees required to perform the activities achieved through the insertion of the PBS flow in these processes by a duplicated operational capacity of the sectors supported by the insertion of automation in the system.

6.2 – Future Steps

The future steps to be taken for the development and final conclusion of the operational validation will come out after a detailed analysis of the stores distribution in PTL sectors as well as the design and support results proposed to extract from the already created and correctly represented simulation model that will serve as a basis for future developments and improvements of each of these operating zones of the warehouse. After the integration of automation suppliers in the project and operational validation being concluded, the aim is to obtain a budget for the project. With this financial information, it shall be proceeded to the ROI and pay-back calculus of the project in order to conclude the financial validation.

After these steps being taken and overall project validation concluded, it is finally proceeded to the implementation of the presented, tested and validated solutions, always keeping in mind that the basis is created not only for this specific project but for further operational and processual improvements to be implemented in these zones of the warehouse.

References

Altarazi, S., Ammouri, M. M. (2016). *Concurrent manual-order-picking warehouse design: a simulation-based design of experiments approach*. International Journal of Production Research,

Altiok, T., Melamed, B. (2010). *Simulation modelling and analysis with Arena*.

Anand, N., Grover, N. (2015). *Measuring Retail supply chain performance: Theoretical model using key performance indicators (KPIs).* Benchmarking: An International Journal.

Ashayeri, J., Gelders, L. F. (1985). *Warehouse design optimization*. European Journal of Operational Research.

Baker, P., Canessa, M. (2007). *Warehouse design: A structured approach*. European Journal of Operational Research, 425-436.

Baker, P., Halim, Z. (2007). *An exploration of warehouse automation implementations: cost, service and flexibility issues.*

Bechtsis, D., Tsolakis, N., Vlachos, D., Srai, J. S. (2018). *Intelligent Autonomous Vehicles in digital supply chains: A framework for integrating innovations towards sustainable value networks.* Journal of Cleaner Production, 60-71.

Bechtsis, D., Moisiadis, V., Tsolakis, N., Bochtsis, D., Vlachos, D. (2017). *Scheduling and control of unmanned ground vehicles for precision farming: A real-time navigation tool*. CEUR Workshop Proceedings, 180-187.

Bimonte, S., Sautot, L., Journaux, L., Faivre, B. (2017). *Multidimensional Model Design using Data Mining: A Rapid Prototyping Methodology.* International Journal of Data Warehousing and Mining.

Boysen, N., Briskorn, D., Fedtke, S., Schmickerath, M. (2019). *Automated sortation conveyors: A survey form an operational research perspective*. European Journal of Operational Research, (3) 796-815.

Buijs, P., Vis F. A., Carlo, H. J, (2014). *Synchronization in cross-docking networks: A research classification and framework.* European Journal of Operational Research, 593-608.

Carmigani, G. (2017). *Scrap Value Stream Mapping (S-MSM): a new approach to improve the supply scrap management process,* 55(12), 3559–3576.

Chen, P., Huang, C., Yu, C., Hung, C. (2017). *The examination of key performance indicators of warehouse operation systems based on detailed case studies.* Journal of Information and Optimization Sciences.

Chiu, Y.-T. H., Fang, S-C., and Tseng, C.-C. (2010). *Early versus potential adopters: Exploring the antecedents of intention in the context of retail service innovations*. International Journal of Retail & Distribution Management, 38(6), 443-459.

Christopher, M. (2016). *Logistics and Supply Chain Management*. (5th Edition). 1, 1-43.

Chung, C. A. (2003*). Simulation modelling handbook: a pratical approach*.

CSCMP, (2013). Supply Chain Management Terms and Glossary, January). 1-222, Website:https://cscmp.org//CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms/CSCMP/Educate/ [Consulted May 2019]

De Koster, R. (2018). *Automated and Robotic Warehouses: Developments and Research Opportunities.*

De Koster, R., & Le-Duc, T. (2007). Design and control f warehouse order picking: A literature review. European Journal of Operational Research, 192(2), 481-501.

Di Tria, F., Lefons, E., Tangorra, F. (2017). *Evaluation of Data Warehouse Design Methodologies in the Context of Big Data.*

Fernie, J., Sparks, L., (2009*). Logistics and Retail Management: Emerging issues and new challenges in the retail supply chain*. (4th Edition). 1, 6-28.

Goetschalckx, M., McGinnis, L., Bodner, D., Govindaraj, T., Sharp, G., Huang, K. (2002). *A systematic design procedure for small parts warehousing systems using modular drawer and bin shelving systems.*

Grande Consumo. (2019). Grande Consumo site, https://grandeconsumo.com/worten-recebe-premio-de-a-melhor-loja-de-portugal/#.XNA_K5xKhaR, accessed 6th May

Gray, A., E., Karmarkar, U. S., Seidmann, A. (1992). *Design and operation of an order-consolidation warehouse: Models and application.* European Journal of Operational Research. 58 (1), 14-36.

Grigoryev, I. (2016). *AnyLogic in three days: A quick course in simulation modelling.*

Gu, J., Goetschalckx, M., Mcginnis, L. F., (2007). *Research on warehouse operation: A comprehensive review*, 177, 1-21.

Gunday, G., Ulusoy, G., Kilic, K., & Alpkan, L. (2011). *Effects of innovation types on firm performance*. International Journal of Production Economics, 133(2), 662-676.

Gupta, Sajal & Randhawa, Gurpreet (2008). *Retail Management.* (1st Edition). 1, 1-31.

Hamberg, R., Verriet, J. (2012). *Automation in Warehouse Development*. 3, 43-89.

Hompel, M. T., Schmidt, T. (2007). *Warehouse Management: Automation and Organization of Warehouse and Order Picking Systems.* 2, 20-62.

Ismail, R. (2008). *Logistics Management*. 4, 47-59.

Kinnear, E. (1997). *Is there any magic in cross-docking?* Supply Chain Management: An International Journal, 2 (2).

Kotler, Philip & Armstrong, Gary (2008). *Principles of Marketing.* (13th Edition). 3 (13), 392-424.

Lambert, D.M. and Cooper, M.C. (2000). *Issues in Supply Chain Management*. 2, 65-83.

Law, A. M., Kelton, W. D. (2000). *Simulation modelling and analysis*.

Lerher, T., Ekren, Y. B., Sari, Z., Rosi, B. (2015). *Simulation Analysis of Shuttle Based Storage and Retrieval Systems.*

Maria, A. (1997). *Introduction to Modeling and Simulation.*

Mahajan, P. S., Ingalls, R. G. (2004). *Evaluation of methods used to detect warm-period in steady state simulation.*

Meller, R. D., Gau, K. Y. (1996). Journal of Manufacturing Systems 15 (5), 351.

Mishra, N., Kumar, V., Kumar, N., Kumar, M. (2011). *Addressing lot sizing and warehousing scheduling problem in manufacturing environment.* Expert Systems with Applications, 38 (9), 11751-11762.

Moeller, k. (2011). *Increasing warehouse order picking performance by sequence optimization*.

Morris, W. T. (1967). *On the art of modelling.*

Mortzis, D., Doukas, M. Bernidaki, D. (2014). *Simulation in Manufacturing: review and challenges*.

OH, S.H., Kim, Y.M., Lee, C.W., and Shim, G.Y. (2012). *Consumer Adoption of Virtual Stores in Korea: Focusing on the Role of Trust and Playfulness*. Psychology & Marketing, 26 (7), 652-668

Oxley, J. (1994). *Avoiding inferior design. Storage Handling and Distribution*, 38 (2), 28-30.

Pantano, E., Viassone, M., (2013). *Demand pull and technology push perspective in technology-based innovations for the points of sale: The retailers evaluation.* Journal of Retailing and Consumer Services, 43-47.

Park, Y. H., Webster, D. B. (1989). *Modelling of three-dimensional warehouse systems*. International Journal of Production Research, 27, 985-1003.

Peixoto, R., Dias, L., Carvalho, M. S., Pereira, G., Geraldes, C. A. S. (2016). *An automated warehouse design validation using discrete simulation.* International Conference on Intelligent Transportation Systems.

Público, 2015. *Cronologia: Acontecimentos marcantes da história da Sonae.* Website: https://www.publico.pt/2015/03/15/economia/noticia/cronologia-acontecimentos-marcantes-da-historia-da-sonae-1689182, accessed 4th March 2019.

Qi, Q., Tao, F., Ang, L., Kusiak, A. (2018). *Data-driven smart manufacturing*. Journal of Manufacturing Systems, 48, 157-169.

Ramaa, A., Subramanya, K. N., Rangaswamy, T., M. (2012*). Impact of Warehouse Management System in a Supply Chain*.

Richards, G. (2018). *Warehouse Management: A complete guide to improving efficiency and minimizing costs in the modern warehouse*. (3rd Edition). 2, 51-80.

Rouwenhorst, B., Reuter, B., Stockrahm, V., van Houtum, G. J., Mantel, R. J., Zijm, W. H. M. (2000). *Warehouse design control: Framework and literature review*, 515-533

Rowley, J. (2000). *The Principles of warehouse design.*

Schmidt, J. W., Taylor, R. E. (1970). *System optimization through simulation*.

Stouten, B., Graaf, A. J. (2004). *Cooperative transportation of a large object – development of an industrial application.* IEEE International Conference on Robotics and Automation.

Schulze, L. Wullner, A. (2006). *The Approach of Automated Guided Vehicle Systems*. IEEE International Conference.

Sprock, T., Murrenhoff, A., McGinnis, L. F. (2015). *A hierarchical approach to warehouse design.*

Tompkins, J. A., Smith, J. D. (2008). *The warehouse Management Handbook*. (2nd Edition).

Van Belle, J., Valckenaers, P., Cattrysse, D. (2012). *Cross-docking: State of the art*. Elsevier: 40(6), 827-846.

Van der Berg, J. P. (2011). *Highly Competitive Warehouse Management*. 3, 43-77.

Varley, Rosemary (2014). *Retail Product Management: Buying and Merchandizing*. (3rd Edition).

Verhoef, Peter C., Kannan, P.K., Jeffrey Inman J. (2015). *From Multi-Channel Retailing to Oni-Channel Retailing: Introduction to the Special Issue on Multi-Channel Retailing*, Journal of Retailing, 91 (2), 174-181.

Wang, C., Quesada-Pineda, H., Kline, DE., Buehlmann, U. (2011). Using Value Stream Mapping to Analyse an Upholstery Furniture Engineering Process, 61(5), 411-421.

Wang, Q., McIntosh, R., Brain, M. (2010). *A new-generation automated warehousing capability*. International Journal of Computer Integrated Manufacturing.

Worten. (2019). Worten Portugal site, https://www.worten.pt/sobre-worten, accessed 23rd February

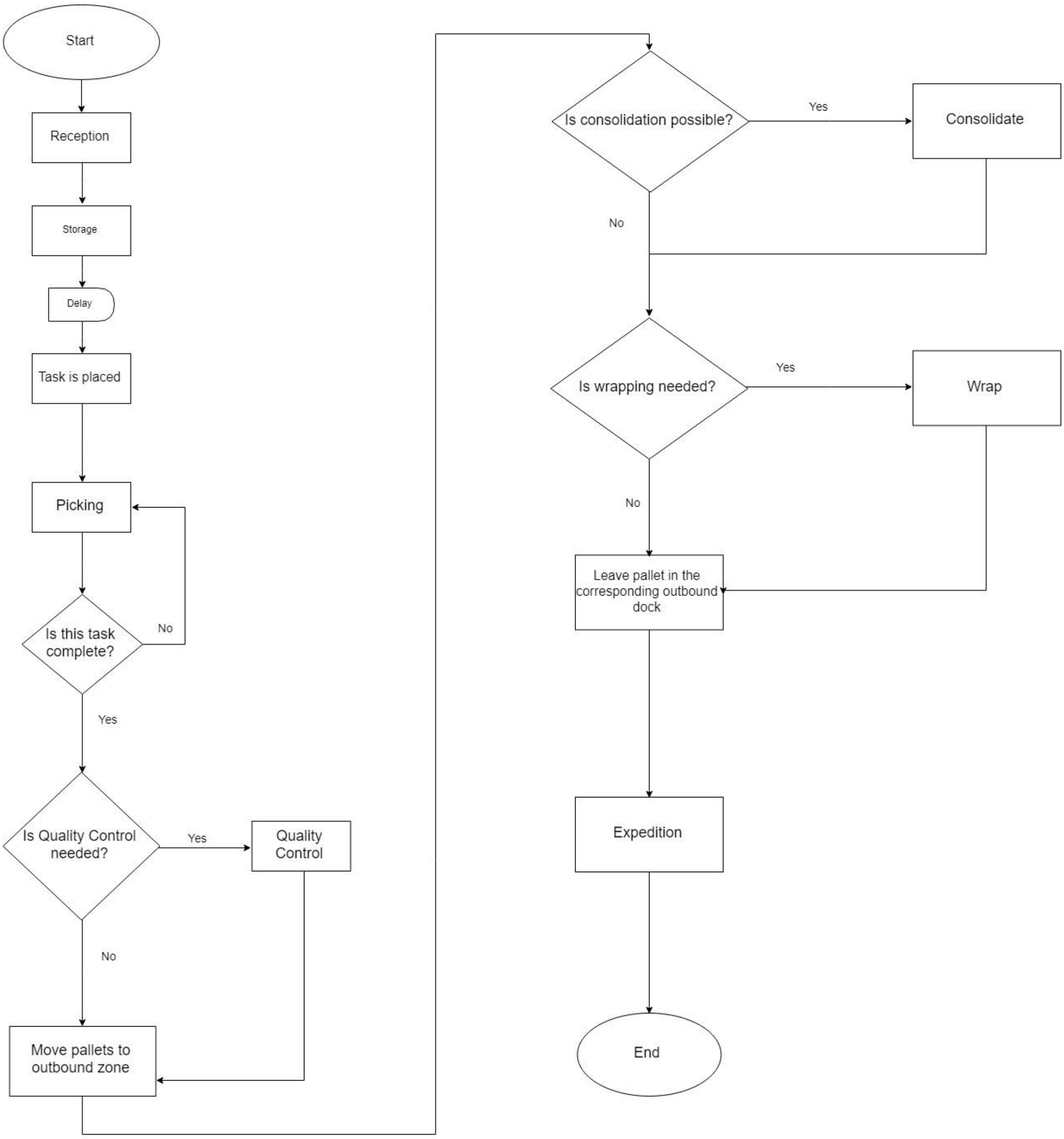
Yoon, C. S., Sharp, G. P. (1996). *A structured procedure for analysis and design of order pick systems.* IEEE Transactions, 28 (5), 379-389.

Zeigler, B. P., Kim, T. G., Praehofer, H. (2000). *Theory of modeling and simulation*.

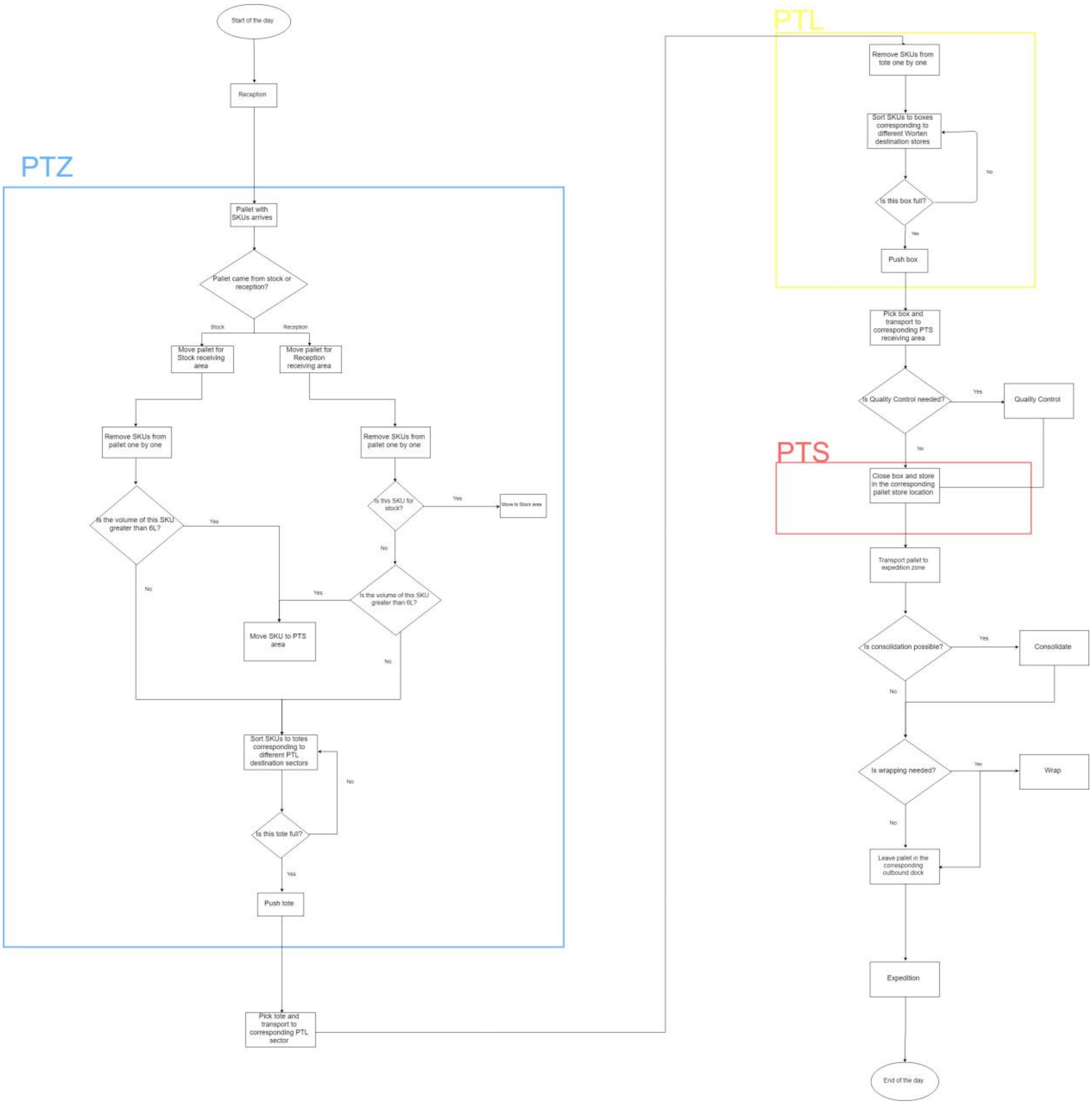
Zentes, Joachim, Morschett, Dirk, Schramm-Klein, Hanna (2007). *Strategic Retail Management*.

Appendix

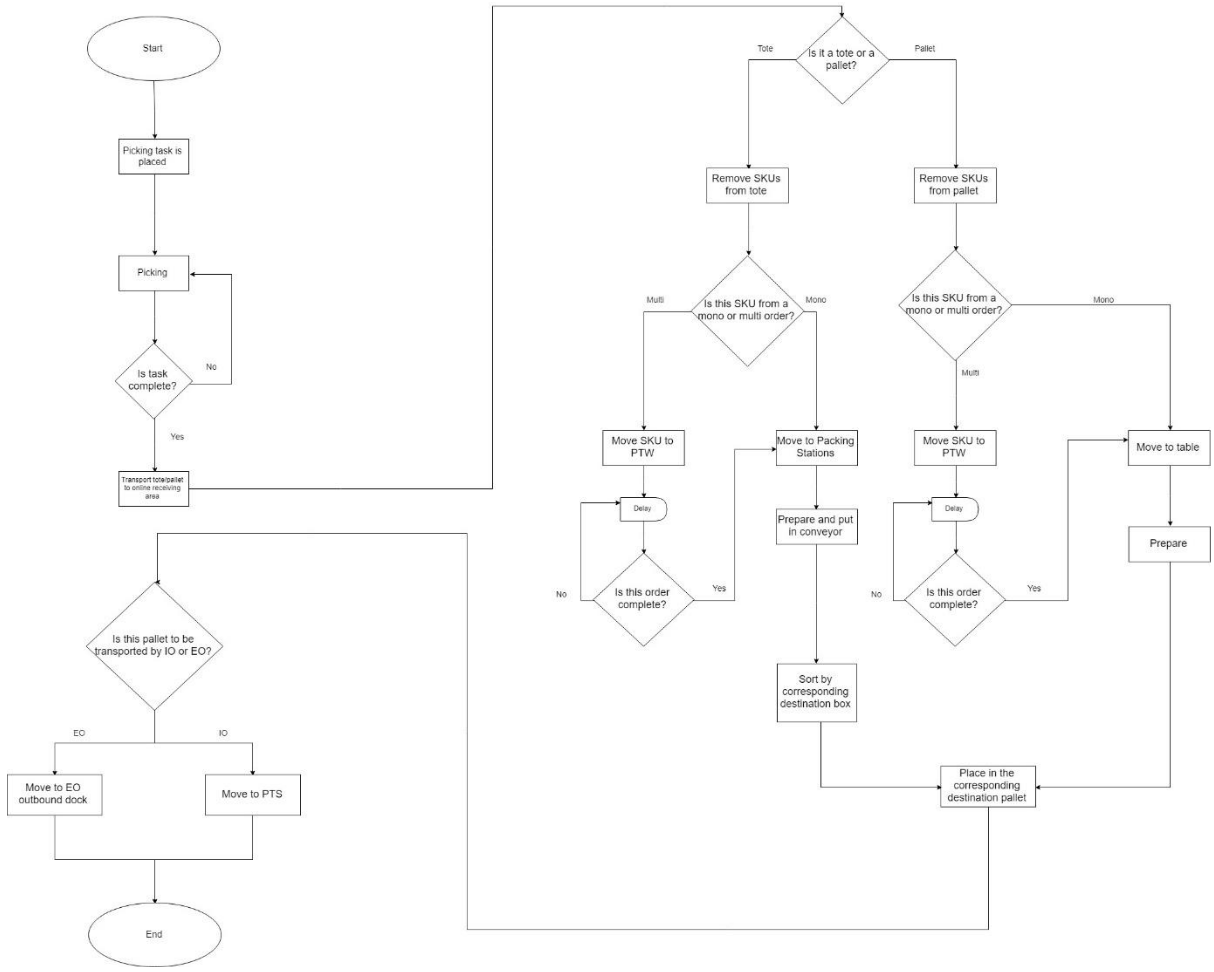
Appendix 1 – PBS flow diagram



Appendix 2 – PBL flow diagram



Appendix 3 – Online flow diagram



Appendix 4 – Project Considerations