# Warehouse Process and Layout Design in a Clinical Diagnostic Network

*Pedro Miguel Baptista Lourenço Balsinha*

**Master's Dissertation**

Supervisor: Prof. Paulo Osswald

U. PORTO

FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

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# Abstract

Healthcare methods and procedures can differ from country to country, nevertheless the maximum purpose remains unchanged, to take care and assist the patient in every way possible maintaining and improving health. The assistance can be handed through various methods including prevention, diagnosis and treatment. Particularly, the company studied works globally towards the same goal, and has become a leader and an example as a company that puts the patient always in first place. The following healthcare company operates in the Clinical Diagnostics market. Despite recent investments in the healthcare sector, companies still do not have maneuvering space to invest and grow to provide an equal healthcare service to everyone. Therefore, every investment, whether it is minor or substantial, must be carefully developed to reach the optimum goal with limited resources.

This project was developed in a clinical diagnostics company that is positioned as on of the leaders within Portuguese borders, as it developed a massive network of clinics, care units and laboratories through the last fourteen years. The project was motivated by an warehousing capacity challenge, that could strengthen the company's network. Business achieved a 24% compound annual growth rate, and the company central warehouse facility, started to show some fragilities handling the required warehousing operations. With almost two thousand SKUs, and a 5% residual consumption growth, the warehouse lacked space and organisation to deal with the network. The aim of this project was to develop a new warehouse layout and redesign the internal processes to apply them to a new and larger facility. After a review of previous related work and significant literature which provided a theoretical insight, it was possible to correlate it with the company supply chain *modus-operandi*. The warehouse operations can be divided into four different stages, Reception, Storage, Order Picking and Dispatch. Each activity was not addressed individually, but rather adopt a Flow principle. Procedures were deeply analysed within the whole warehousing activity to understand effects, benefits or disadvantages they may bring to the entire operation. The development of this project ended up with a proposal of a reorganisation of warehouse layout and redesign of the physical flows and work procedures.

The resulting layout and process development was conducted in order to provide an adequate warehousing structure, by improving physical flows, diminish lost items and provide the requested goods to the laboratory situated in the same building or to all care units scattered along the network. Key KPIs were established to provide a quantified evaluation of the proposed solution.

# Resumo

As metodologias e os processos adotados na área da prestação de cuidados de saúde podem sofrer variações de país para país. Seja como for, o seu propósito principal permanece constante. Cuidar e assistir o paciente, de todas as formas possíveis, e de forma a preservar e a melhorar a sua saúde. A assistência ao paciente poderá ser decomposta em vários métodos, incluindo a prevenção, o diagnóstico e o tratamento. Em particular, a Empresa em estudo trabalha globalmente em torno de um só objetivo, e tornou-se uma empresa líder e exemplar, por colocar sempre o seu paciente em primeiro lugar. A empresa de prestação de cuidados de saúde aqui em causa opera no mercado do diagnóstico clínico. Apesar de investimentos recentes nesta área, as empresas do setor permanecem sem qualquer "espaço de manobra" para investir e crescer, de forma a providenciar cuidados de saúde iguais para todos. Deste modo, todo o investimento, seja ele reduzido ou substancial, deverá ser cuidadosamente explorado, de forma a se poder atingir, com recursos limitados, o objetivo ótimo.

Este projeto foi desenvolvido numa empresa de diagnósticos clínicos que se posiciona como um das principais líderes no mercado português, posicionamento esse que se explica pelo desenvolvimento, ao longo dos últimos catorze anos, de uma rede massiva de clínicas, unidades de cuidados e laboratórios. A motivação deste projeto passou por um desafio ao nível da capacidade de armazenamento, de forma a se conseguir fortalecer e garantir um maior suporte a esta mesma rede. Com efeito, quando o negócio atingiu uma taxa de crescimento anual na ordem dos 24% nos últimos anos, o armazém central da rede começou a revelar algumas debilidades e a incapacidade para acompanhar as necessidades sentidas ao nível das operações de armazenamento dos dois mil SKUs. O objetivo deste projeto consistiu em desenvolver um novo layout para o armazém e redesenhar os processos internos, de forma a aplicá-los a uma nova e mais extensa unidade. Após análise de trabalhos prévios relacionados com o presente, e da revisão da literatura mais significativa, existente a este propósito - que possibilitou uma perspetiva teórica sobre o tema - foi possível correlacioná-la com o modus operandi da cadeia de fornecimento da empresa. De facto, as atividades de um armazém podem ser divididas em quatro processos principais: Receção, Armazenagem, Preparação de Encomendas e Expedição. Cada uma das atividades não foi considerada, per se, individualmente, antes se havendo optado por uma perspetiva fluida. Os procedimentos foram analisados em detalhe, no contexto global da atividade de armazenagem, de forma a possibilitar uma compreensão sobre os efeitos, vantagens e desvantagens que os mesmos podem aportar à atividade. A execução deste projeto findou com a proposta de um novo layout para o armazém, acompanhado do redesenhar de todos os fluxos físicos e informáticos, bem assim dos procedimentos de trabalho.

O layout proposto e a delimitação dos processos foram conduzidos, de modo a assegurar uma estrutura de armazenagem adequada, através do aperfeiçoamento dos fluxos físicos, com isso se diminuindo as perdas e assegurando a distribuição dos bens necessários, tanto ao laboratório situado no mesmo edifício, como a todas as unidades de cuidados integrantes na rede. Por fim, foram estabelecidos KPIs, como forma de garantir uma avaliação quantitativa da solução proposta.

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*"No man knowledge can go beyond his experience."*

John Locke

# Contents

# Acronyms and Symbols

| | |
|---|---|
| ABC | Activity-Based Costing |
| FEFO | First-Expired First-Out |
| FIFO | First-In First-Out |
| FTE | Full-Time Equivalent |
| KPI | Key Performance Indicator |
| PDA | Personal Digital Assistant |
| ROI | Return on Investment |
| SKU | Stock Keeping Unit |
| TFM | Total Flow Management |
| TPS | Toyota Production System |
| WMS | Warehouse Management System |

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# Chapter 1

# Introduction

Healthcare has come to mean every aspect, service, intervention, or device for taking care of your health. Countries and companies' expenditure in healthcare has risen due to a greater focus on people's health and quality of life. Since equipment and procedures are expensive, one of the most advantageous ways for healthcare providers to assure affordable prices to patients is to form clusters of enterprises and obtain cost advantages through organized supply chains and economies of scale. These two factors have leading roles in solving the cost-quality equation of healthcare. By growing and reaching more people, healthcare companies can increase their revenues. These revenues can then be used to negotiate with suppliers lower prices for bigger quantities of goods and increase the competition and specialization within doctors and other technicians. To achieve this scale, healthcare companies like Unilabs, specialized in the clinical diagnostics business, must grow substantially. This market growth must always be accompanied by a robust structure the sustains and supports the business itself. Warehousing has represented, throughout history, this foundation to physical businesses. Even though that some companies are successfully getting further away from the need for these infrastructures, in healthcare, it is presently impossible to deny its major role.

With the rapid growth in recent years, Unilabs has established a network of more than one thousand care units, clinics, and laboratories that provide an essential service to the Portuguese population scattered throughout the country. The growth of this network must be supported by the development and expansion of the warehousing activities. The present study, integrated into the Supply Chain team of Unilabs, arose as a need to adapt the Central Warehouse in Porto, Portugal, Headquarters to the northern network of care units. The current warehouse was not able to deal efficiently with the required service level as the available space was not sufficient. The main focal point of this project is to design a new warehouse layout for the network and rethink and develop all the correspondent activities.

The present chapter will provide a deeper overview of the company and the project in order to clarify the main and secondary objectives.

## 1.1 Company Overview

Founded in 1987 as a merger of three clinical diagnostic laboratories in Switzerland, Unilabs has grown rapidly ever since, following a strategy of acquiring high-quality partner laboratories across Europe. In 2007, Unilabs merged with the major imaging diagnostics company Capio, whose reach encompassed Sweden, Norway, Finland, Denmark, and the UK. This merger positioned Unilabs as the undisputed European leader in diagnostics. The company continued to invest and expanded beyond the European borders through a M&A policy, and upgraded the portfolio with cutting-edge diagnostic technology establishing new offerings in genetic medicine and pathology.

Nowadays, Unilabs aggregates more than 250 laboratories that employ around 12,000 members and 1,300 doctors. The company is one of the largest diagnostic providers in Europe, and the only provider to offer laboratory, imaging, and pathology specialties within the same group, performing 195 million laboratory tests annually.

Unilabs entered the Portuguese market with the acquisition of 85% of *Medicina Laboratorial Carlos Torres*, which gave the company a head start in terms of clients and infrastructure to expand in the country. M&A policies were the main rationale behind the expansion in the last years, moreover, the acquisition of *Base Holding* in 2017 turned Unilabs into one of the biggest players in clinical analysis in Portugal. Nowadays Unilabs incorporates various diagnostics services such as genetics, nuclear medicine, radiology, pathological anatomy, cardiology, and gastroenterology. Figure 1 clearly demonstrates the magnitude of this company in the healthcare sector in Portugal in the year 2019. From 2017 to 2019, the company registered a 24% compound annual growth rate nationally.

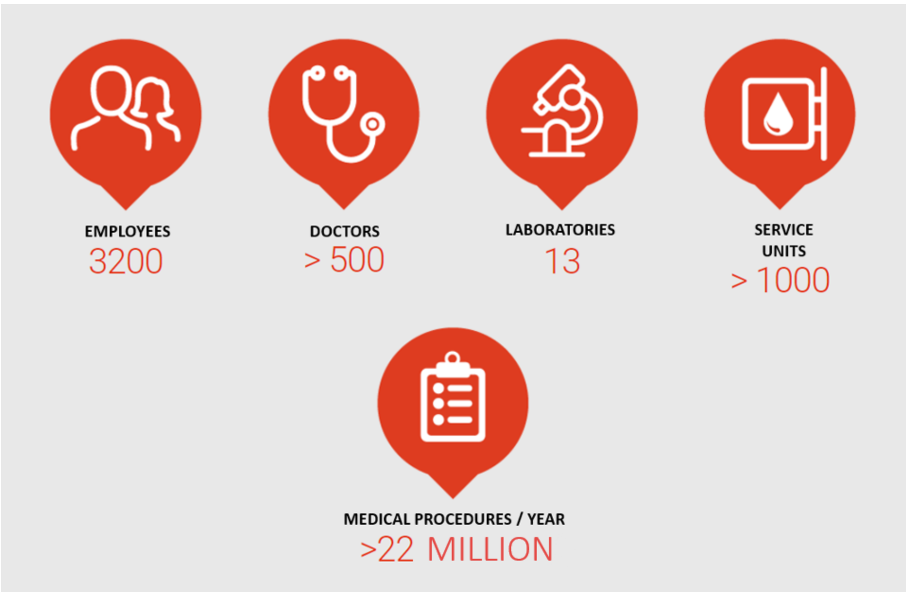


Figure 1: Unilabs by the numbers

Since 2017, Unilabs follows the CARE BIG mantra. This motto encourages every employee to focus on the needs of customers, as they depend upon the company's performance and operation. CARE BIG is not simply processing samples, but finding answers that help improve people's lives.

## 1.2 Project Motivation

The primary focus of this project is to improve and adequate the central warehouse layout and processes in order to support the growth of the company in the next years.

Due to rapid growth and expansion, the size of the central warehouse is not capable to efficiently store the consumables and supply them to the 690 units and clinics incorporated in the network. This expansion of the storage facility is included in the company's plan to centralize distribution in four warehouses in Portugal. The warehouse in Porto will continue to supply 690 units, a second warehouse will be established in the region of Coimbra, the region of Lisboa has already a network served by a warehouse finally, the most southern units will be supplied by a future facility in the region of Algarve. In 2012 the central warehouse occupied and area of 100 square meters. Until the year of 2016, the same facility absorbed another 80 square meters. In 2019 occurred the final expansion of the present warehouse, to 220 square meters. However, the expansion, due to physical constraints, can no longer continue.

The aim of this project is focused mainly on the tactical and operational levels as strategic decisions were given as input data.

Therefore, the main objectives are to firstly reorganize the processes of the Warehouse Management department and adapt their framework to the current demand. Secondly, to design the layout and incorporated areas of a new storage facility in Porto, Portugal. This space shall be dimensioned to hold and control all SKUs and the corresponding stock and provide space for future consumption growth. The SKUs shall be assigned to a storage location respecting their rotation, volume, and usage. A new picking method was adopted. Subsequently, all material and information flow, adjacent to the department and facilities, including a new picking method, is to be reviewed to allow for an efficient fulfillment of the demand across the network.

## 1.3 Methodology

The project can be divided intp three stages. The initial stage was based on a study and overview of the processes and flows of the current warehouse operations. Tasks were timed, quantities were evaluated and responsibilities identified and addressed. After retrieving this information, the next step was to evaluate throughput requirements, inventory levels and customer service levels. These initial examinations of the current situation led to the second stage, of evaluating the space and resources available for the project. Within this stage, meetings were held with the company project leaders so they could transfer to this work all the required inputs. This stage including building a structured background knowledge for this work with the review of essential literature and the state of the art. Finally, the last stage began by reorganizing all the gathered information and start to develop the warehouse. The current warehouse processes were reviewed, and the layout was designed through a series of iterations. These iterations were not only defined by requirements calculations but just as well by creative activities. Finally, the equipment and further requirements were carefully specified to match the final design.

## 1.4 Thesis Outline

The current chapter focuses on the rationale behind this thesis and its objectives as well as an overview of Unilabs and its history since the foundation until the current development in Portugal.

Subsequently, this thesis is divided into four more chapters with the following structure:

Chapter 2 provides a review of the state of the art for the most relevant themes to be developed and implemented throughout the thesis.

Chapter 3 describes in great detail Unilabs main processes and flows within the thesis context, followed by the limitations identified throughout the processes and a brief summary of the proposed future scenery.

Chapter 4, firstly pursues the revision of the warehousing processes and the following adjustment to the new flow, followed by the design of the new layout. A detailed iterative process then takes place to adapt the processes and flow to the new facility.

Chapter 5, finally refers some conclusions about the analysis performed and the options considered. A final reflection is taken onto possible future work.

# Chapter 2

# Literature Review

The overall goals of this chapter were first to establish the significance of the general field of study and converge into the paramount themes, laying down support to develop this thesis. A first introduction to Supply chain and Warehousing management is essential. This chapter will next deal with the main processes and activities and the layouts of warehousing in the industry, as these topics have a clear impact on this project. Also, a light focus is set on the 5S program and how lean principles hold significant importance to the operations inside the warehouse. Finally, the most relevant KPIs to sustain future procedures are addressed and described.

## 2.1 Supply Chain

A supply chain is the network of two or more organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer. According to Richards (2011), supply chain is constantly driven by this major trade-offs:

- Cost versus service;
- Storage capacity versus speed of retrieval;
- lower inventory versus availability;
- Efficiency versus responsiveness;
- Volume purchases versus storage cost and availability;
- Speed versus accuracy;
- Team productivity versus turnover rate.

In the healthcare sector, the consumers are represented by the patients and the service they want is their improved health at best. Typically, a healthcare supply chain is a multi-echelon, multi-item inventory system (Rossetti and Liu, 2009). It frequently consists of four layers of :

- External suppliers including wholesalers and manufacturers;
- A consolidated service centre, which acts as a group purchasing organization. This player purchases directly from various suppliers and stocks the products.
- The third player is the service unit, which can be part of the same company of the player above, an independent clinic, pharmacies or hospitals.
- At the end of the chain, the final player, customers drive the system.

Thereby, the Healthcare Supply Chain is a stream of processes, workforce, equipment and goods, that are needed at the right time at the right moment in order to connect all the internal tasks and duties and suppress vulnerabilities among the process, therefore the patient can experience the best possible service.

## 2.2 Lean

Lean provides a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively. In short, lean provides a way to do more with less human effort, less equipment, less time, and less space while coming closer and closer to providing customers with exactly what they want (Womack and Jones, 2003). As Coimbra (2009) concluded, lean means to employ minimum resources for maximum output.

### 2.2.1 Lean in Healthcare

Lean in Healthcare is about improving patient's health condition within the minimum time possible at the lowest cost. By improving safety, reducing waste and waiting times it creates value within the services.

Within healthcare, and in particular in clinical diagnosis, the major concerns go towards patient satisfaction, reliable information that supports health improvement, lead time of processes such as admission, collection and delivery, and finally, the satisfaction of the professionals involved, as all of these represent the natural procedure and well being of the company. According to Venkateswaran et al. (2013) Lean have the potential to bring four benefits to the healthcare service: improved quality and minimized mistakes, reduced time to deliver work; improved throughput, as the same amount of professionals using the same equipment are able to achieve a greater amount of work; and a reliable working environment with a standardized agenda. By applying these specific enhancements, the overall goal of healthcare, superior patient care will be delivered.

### 2.2.2 Lean Warehousing

Concerning the warehouse environment, improving lean activities and processes, it requires to identify the activities within the warehouse that absorb resources but do not create additional value. As stated by Sutherland and Bennett (2007) the eight wastes of a warehouse are:

- Over storage: Storage more than is needed for near future use;
- Delay/Waiting: Any delay between the end of one process and the start of the next activity;
- Transportation/Conveyance: Unnecessary movement of products, materials or information.
- Motion: Unnecessary movement and effort of people, such as walking, reaching and stretching;
- Inventory: Any raw material, work-in-process, or finished goods that exceed what is required to meet customer needs just in time and to maintain process stability;
- Over-processing: Using more energy than what is needed to process an activity - or adding more value than the agreed standard;
- Defects: Any activity that results in the need for rework or scrap;
- People: Waste of capability and potential of stakeholders.

Wastes should be minimized in order to streamline the process of receiving an item, store it, receiving the request, and dispatch it, adding extra value to the supply chain.

### 2.2.3 Total Flow Management

The total Flow Management model was implemented by Toyota with the objective of smoothing the implementation of the company's Production System based on the creation of pull flow principles. This means that supply chains are pulled by customers' orders creating a continuous flow of materials and information along the chain, including the warehousing sector.

Storage and warehousing design represent the first step of the External Logistics Flow pillar. The main goal in this step is to eliminate all types of *muda*, waste, and create a value-added service for customers along the chain. A warehouse should be designed to allow an efficient flow of materials. To achieve an optimal situation, the space use must undergo continuous improvements, by organizing designated zones according to products movements (Coimbra, 2009).

Coimbra (2009) also enumerates the flow principles of a warehouse:

- Product is stored by type and turnover in storage cells;
- Layout is flexible;
- System uses visual management;
- There is one product-specific storage location for the necessary time;
- Abnormalities should be minimum;
- Allows for the storage of delivery packages.

After activities and processes are reviewed, it is extremely important to sustain them and verify that people do not return to old habits. By creating a smooth flow model, all the players should be able to reduce the total lead time and this reduction represents a decrease in costs and working capital. On the other hand, quality and productivity increase resulting in higher service levels and customer satisfaction (Coimbra, 2009).

### 2.2.4 5S Program

5S is a system for organizing and standardizing the workplace. Ho (1999) described 5S as a technique to establish and maintain a quality environment in an organization. 5S is a team-based inexpensive process improvement tool that focuses on creating order in the work environment, and in turn supports error proofing, visual management, and preventive maintenance. The merge of all the S, Seiri (Sort), Seiton (Simplifying), Seiso (Shine), Seiketsu (Standardize) and Shitsuke (Self-discipline) represent an overall improvement for the workplace and the company. Inside a warehouse, the company should be able to identify and surface issues quickly, address their root causes, and prevent recurrence. If replenishment is needed, if something is out of place, if tasks are being done incorrectly, 5S can identify these issues and surface them for quicker resolution.

## 2.3 Warehousing

### 2.3.1 Warehouse management

According to Richards (2011) a warehouse should be a trans-shipment point where all goods received are dispatched as quickly, effectively and efficiently as possible. Coimbra (2009) claims that the main objective of a warehouse is to synchronize the offer of available product with customer demand, maintaining a minimum amount of goods waiting in inventory.

An exemplary management should always take into account the efficiency and productivity whilst reducing costs, improve quality, reduce reception, picking and dispatch lead times, taking care of workforce management, health and safety without forgetting the effects caused by technological progress and sustainability of the activities and the business.

### 2.3.2 Warehouse processes design

Regardless of the industry in which the company operates, some activities must always be present in the warehouse. With the entrance of products, the following activities, receiving, put-away and storage are set off. On the other hand, an order request triggers picking, checking, packing and shipping/dispatching. An efficient flow of goods is mandatory for every storage facility. Figure 2 exhibits how the operations are stratified.

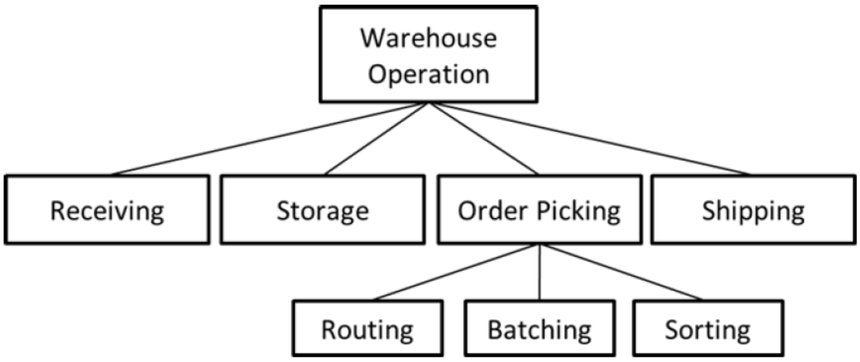


Figure 2: Warehouse operations

**Reception**

Receiving, goods-in or in-handling is a crucial process within the warehouse. Ensuring that the correct product has been received in the right quantity and in the right condition at the right time is one of the mainstays of the warehouse operation (Richards, 2011). This process involves the physical unloading of incoming transport, checking, and recording of receipts. It can also include such activities as unpacking and repackaging in a format suitable for the subsequent warehouse operations. Quality control checks may be undertaken as part of this activity. From here, the goods are then put away in the warehouse (Rushton, 2010).

**Storage**

After goods enter the storage facility, they are normally taken to the reserve or back-up storage area, usually occupying the largest space in warehouses. This area holds the bulk of warehouse inventory in identifiable locations, consequently, it is extremely important to reduce non utilized space and stock.

In order to develop an efficient picking process, a great deal of preparation needs to take place beforehand. Correct storage of products, will not only have an impact on the product itself but also the flow of the activities along the warehouse floor. Placing products in the most appropriate location reduces travel distances and strain on operatives and as a consequence leads to improved productivity and overall cost reduction (Richards, 2011).

As the healthcare industry deals with a great diversity of items, some are not suitable for palletization as the can be too small or fragile to have stacked items on top or represent an arduous picking. For small items, there is a range of solutions designed for storage such as shelving, drawer units and carousels. The major emphasis must be to arrange a specified location for each SKU or adopt a dynamic method supported by a warehouse management system Rushton (2010).

**Order Picking**

Order picking involves the process of clustering and scheduling the customer orders, assigning stock on locations to order lines, releasing orders to the floor, picking the articles from storage locations and the disposal of the picked articles. Customer orders consist of order lines, each line for a unique product or stock keeping unit (SKU), in a certain quantity (de Koster et al., 2007). The most common objective of order-picking systems is to maximize the service level subject to resource constraints such as labour, machines, and capital. A crucial link between order picking and service level is that the faster an order can be retrieved, the sooner it is available for shipping to the customer (Goetschalckx, M., Ashayeri, 1989).

Richards (2011) suggests that order picking is the most costly activity within today's warehouses. Not only is it labour intensive, but it is challenging to automate, can be difficult to plan, is prone to error and has a direct impact on customer service. Therefore, it is the most targeted area for productivity improvements in order to improve the overall costs. de Koster et al. (2007) suggests that for specific activities the cost of order picking is estimated to be as much as 55% of the total warehouse operating expense. To achieve effective standards, a series of correlated decisions need to be taken and must be appropriately aligned. Figure 3 shows interrelationships between the four factors that influence warehouse operations.

When receiving an order, a picker, either automated or manual, is dispatched to pick the appropriate quantity of each item from its storage location and bring them back to the shipping area. Finding a way to minimize the distance or time traveled by the picker is a common objective.

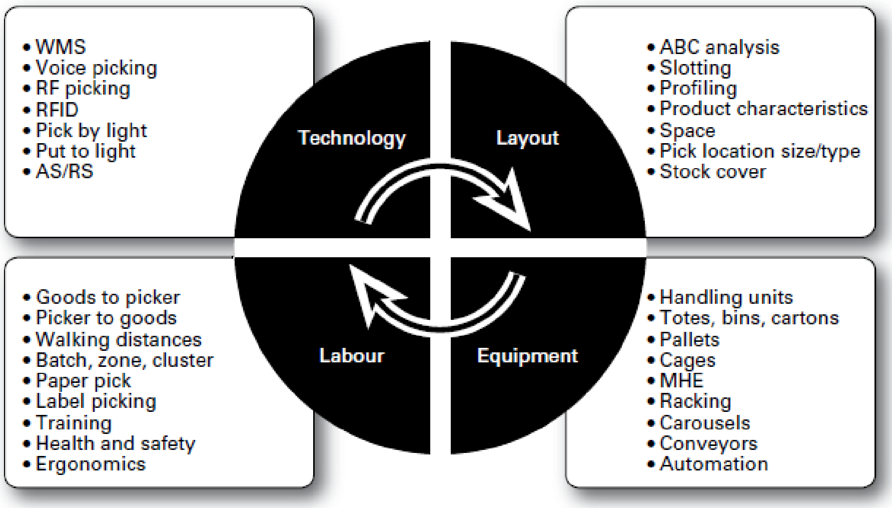


Figure 3: Four factors that influence warehouse operations (Richards, 2011)

A picking strategy defines the manner in which pickers navigate within aisles of a picking area to pick up required items. The basic order picking strategies are single picking (also discrete picking), batch picking, zone picking, and combinations of the above (e.g. zone-batch picking). Single picking is a strategy in which a picker picks all items from a single order during a single pick-tour. This policy is preferred because it is easy to implement and maintains order integrity.

Single picking performs well with a small number of orders and a high number of picks per order. Picking orders with small number of picks (per order) will lead to an excessive travel time. On the other hand, in batch picking, several orders are batched (grouped) together. Pickers pick all items (from a given batch) in a single pick-tour. Batch usually includes a few to several orders. It depends on the average number of picks per order and a size of picked items. Batch picking systems may use algorithms that are useful for grouping orders(Klodawski et al., 2018). Therefore, de Koster et al. (2007) claims that under time window batching, the orders arriving during the same time interval (fixed or variable length), called a time window, are grouped as a batch. These orders are then processed simultaneously in the following stages.

Picking problems have led to the development of several numbers of strategies and correlated equipment, each one with advantages and drawbacks. One of the main cost areas within the picking operation is the movement between pick locations. Depending on the operation, this can account for up to 50 per cent of a picker's time, thus the aim is to reduce the amount of travel (Richards, 2011). In order to be productive and efficient in the picking process, a great deal of preparation needs to take place. This includes having a comprehensive understanding of the products and their sales patterns and the data available to produce ABC analyses.

**Dispatching**

Client loads are marshaled together to form vehicle loads in the dispatch area and are then loaded on to outbound vehicles for onward dispatch to the next 'node' in the supply chain - to an intermediate distribution centre, to a port or airport for the next transport leg, or directly to the final customer. Inside the warehouse, the space needed for all of the activities listed under receiving and dispatch processes should be estimated and laid out. This should not be underestimated, as quite frequently a total of 20 per cent to 30 per cent of the floor area needs to be allocated to these activities to facilitate the efficient flow of goods into and out of the warehouse (Rushton, 2010).

### 2.3.3 Warehouse layout design

As the competitiveness and demand increase, warehousing space becomes more expensive, therefore an efficient and wise use of the same space is imperative for every company. In effect, warehousing usually represents about 20 to 30 per cent of logistic costs (Rushton, 2010). Continuous evolving and shape changing products require warehouses to be quite flexible and adjustable. The design of a warehouse and handling system involves several of stages, starting with the definition of system requirements and constraints, and finishing with an evaluated preferred design (Rushton, 2010). There is no such thing as a perfect design solution for every warehouse. In order to provide a detailed evaluation and characterization of the warehouse, firstly it must be observed through three different angles: processes, resources, and organization. Products arriving at a warehouse subsequently are taken through a number of steps called processes. Resources refer to all means, equipment and personnel needed to operate a warehouse. Finally, organization includes all planning and control procedures used to run the system (Rouwenhorst et al., 2000).

A warehouse design runs from a functional description, through a technical specification, to equipment selection and determination of a layout. In each stage, target performance criteria (costs, throughput, storage, capacity and response times) have to be met (Rouwenhorst et al., 2000). A well-designed warehouse should reduce the total traveled distance, and at the same time take into account opportunity costs and future expansion and development. As Rouwenhorst et al. (2000) admits, the prominent design criterion is the maximum throughput, to be reached at minimum investment and operational costs.

A detailed design of the warehouse requires loading and unloading bay, reception, storage, picking area and dispatch area. In order to smooth the design process, a number of factors should be prioritize such as data gathering, cubic capacity, health and safety standards, movement minimization, packaging standardization and future expansions (Richards, 2011). The main objectives taken into account when designing and optimizing a warehouse are: minimize the throughput time of an order; maximize the use of space; maximize the use of equipment; maximize the efficiency of labour and maximise the accessibility to all items (de Koster et al., 2007) Inefficiently planned activities such as preparation, transport and storage of products inside a warehouse, undesirably increase traveled distance, therefore the layout should keep the areas with a higher rate of interactions close by, this way the human resources are being more efficiently managed.

### 2.3.4 Inventory management

According to The Council of Supply Chain Management Professionals, inventory management is the process of ensuring the availability of products through inventory administration. Inventory management is critical to any business, as a supply chain with zero amount of stock from raw materials to the final consumer is an ideal situation that hardly ever happens. Markets and consumers are unpredictable, consequently products must be stored in adequate conditions in order to be picked, maintaining an appropriate stock level to avoid shortages and oversupply. An inconsistent management may cause potential delays, dissatisfied customers and loss of capital due to expired perishables products and the reduction of cash flow invested in tied up stock. The overall goal is to make the right product available to the user at the right moment and place (Reichhart and Holweg, 2007). In the specific case of a healthcare warehouse, this receives an even more relevant meaning, as operations are subjected to uncertain demand, and the right medicine at the right time may be crucial for a patient. As it is customer-driven, a certain product may be demanded virtually without it's presence in the system, contributing to a proliferation of SKUs. Furthermore, healthcare services have quite a high variance, as some seasons of the year represent an increased affluence to hospitals and healthcare centres than others. Viral outbreaks are also a powerful trigger to this inconsistent demand. Taking all into consideration, the healthcare business faces a complex stock management with various SKUs that may have uncertain demands and may suffer from seasonal changes. In case of a shortage, an emergency delivery is necessary and this emergency refill is very costly and can have effects on the patient's healing process, therefore, some drugs that represent a crucial part if the patient's treatment must have a substantial service level. (Kelle et al., 2012).

Due to the European Medicine Agency (EMA) regulations for the pharmaceutical and healthcare industry, an item is retrieved based on the first-expired, first-out (FEFO) principle. This means that for an item, SKUs with the nearest expiration dates should be picked from stock first (Khodabandeh, 2016). Thus, an organized and well-structured warehouse in this sector must account for the expiry date.

#### ABC Classification

Several inventory management techniques are in practice today and are either deterministic or probabilistic. The ABC classification is a widely used inventory management tool to classify SKUs that enables the identification of critical and least important supplies based on various criteria, such as rotation, volume and dollar usage. The most important supplies in terms of dollar usage are placed in group A, which demand the greatest effort and attention from management; the least important SKUs fall into group C. The remaining ones belong to the middle group B. This classification rests on the "80-20 rule" which suggests that the number of SKUs in A (80% of the total usage), represent only 20% of the inventory (Chen et al., 2008). Unfortunately, the ABC classification is not enough, there is also important to classify items by uncertainty with an XYZ analysis. This way, it is possible to identify products at risk, whether it is a risk of shortage or overstocks to define the right inventory coverage. Very stable and predictable products are classified as X, Y are less stable, and finally, Z products are completely unstable and totally unpredictable due to irregular consumption (Scholz-Reiter et al., 2012).

### 2.3.5 KPI's in a warehouse

Ensuring customer satisfaction is a critical rationale that causes companies to measure performance. Good warehouse productivity will improve quality performance, delivery time, customer satisfaction and reduce cost in logistics system (Marco and Mangano, 2011). Additionally, the usage of KPI's for performance measurement ensures that the evaluation of the activity is compared with a benchmark. Therefore, any sort of variation in performance is immediately perceptible, reducing the time of reaction.

According to Ackerman (2003), performance measurement can be separated into four major groups: efficiency, effectiveness, input and output, whereas reliability, flexibility, cost and asset utilization should be the four areas measured within a warehouse (Ackerman, 2003). Kusrini et al. (2018) concluded that the most effective KPI's for a warehouse environment should be productivity (receive per man-hour) for receiving, cycle time for order picking, utilization for storage and productivity for shipping.

#### Return on Investment

Prior to any significant investment, the total costs shall be analyzed. Return on Investment is a valuable measure to assess the efficiency of an investment, and can be applied as a KPI for a warehouse project. It is exceptionally useful for measuring success over time and taking the guesswork out of making future business decisions. ROI measures the amount of return on a particular investment, relative to the investment's cost. A negative value, indicates that the investment will result in a net loss. On the other hand, a result of 100% means that the amount of the return equals the amount of the money invested. To achieve a detailed calculation it is essential to consider all investment costs, plus operating costs, and estimates of gains to be made in corporate image, customer services, control, etc (Botchkarev et al., 2011).

$$ROI = \frac{Gain\ from\ investment\ (or\ savings) - cost\ of\ investment}{cost\ of\ investment \times 100} \quad (1)$$

Therefore, ROI is an important element that needs to be considered when planning a future storage solution for a company, comparing the current situation with the project under assessment.

### 2.3.6 Warehouse costs

Warehousing is under constant pressure to reduce costs and increase the number of SKUs. The operating costs of a warehouse range between 1 and 5 per cent of the total sales, this value is subject to the type of company and worth of goods, as a pallet of goods occupies the same space independently of its value (Richards, 2011). In order to fully portray the cost of a warehouse process, costs and cost drivers must be carefully established. The major types of costs are: rental utilities, direct and indirect labour, equipment and overhead costs. Within these groups, the costs may be fixed or variable. Rushton (2010) estimates the annual warehousing costs as the following:

1. Staff - up to 50 per cent, of which half is accounted for by the order picking;

2. Building (rent or equivalent) - 25 per cent;

3. Building services (maintenance, services, insurance, rates) - 15 per cent;

4. Equipment - 10 to 15 per cent.

# Chapter 3

# Problem Context

The first part of this chapter aims to provide a detailed context for the project, by a detailed description of the company, the warehouses, structure and main operations.

Along with the description, the observed problems and limitations throughout the chain of activities are addressed and discussed. The analysis of the warehousing activities will follow process sequence, as every activity is directly linked to and dependent on the previous and following. Therefore, it is unfavorable to scrutinize an activity by its own without taking into consideration the chain of action inside and around the storage facility. The flow of information is of utmost importance to be analysed within each section of the process to carefully understand it's role.

After the AS-IS situation is described, the final section of the chapter, states the requirements of an expected TO-BE standpoint after this project.

Unilabs is an agglomerate of approximately one thousand clinics, labs and various care units that were independent in the past. Therefore, the company's stream of material and information, from purchase until delivery, is somewhat complex. Unilabs provides a wide array of medical diagnosis, specialties, and procedures which results in a high variability of items. Laboratories have the autonomy to request unusual or new materials directly to the suppliers, without the approval of the Headquarters. The flow of such process can be seen in figure 4.

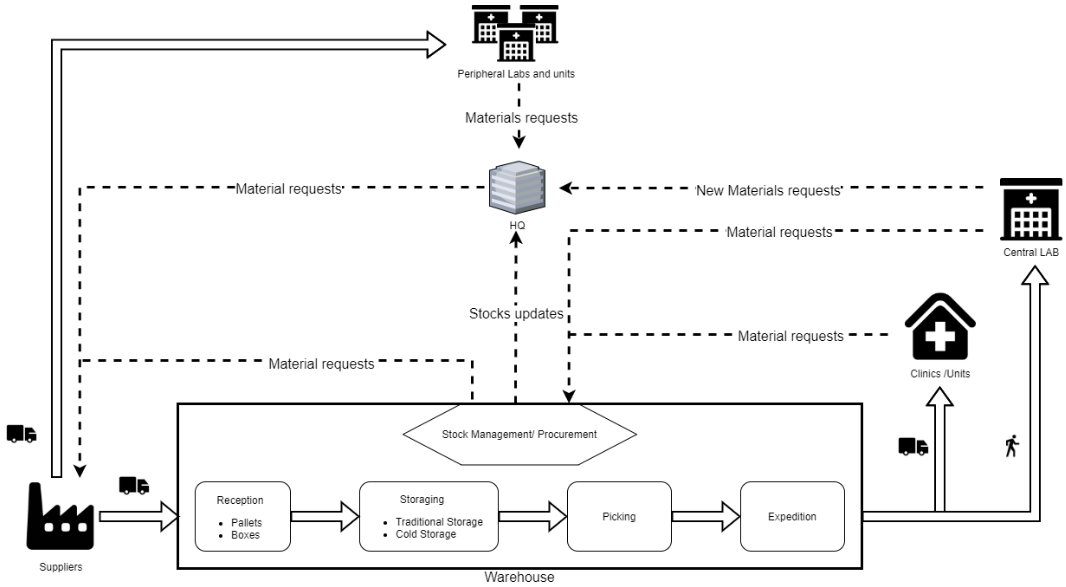


Figure 4: Unilabs chain of process

620 units including the Central Lab in Porto, are supplied by the Central Warehouse network. Therefore, this facility must be able to meet its demand throughout the year, taking into account seasonality and peeks. The current main KPI of the warehouse is the percentage of completed orders with at least one missing item. Currently, the warehousing process recorded a value of 60%. Table 1 clearly describes the daily statistics about the completed orders in the central warehouse.

Table 1: Descriptive statistics of completed orders per day

| | |
|---|---|
| Average | 80 |
| Max | 120 |
| Min | 32 |
| Standard Deviation | 7,76 |
| Lines per order (SKU) | 11,46 |

## 3.1 SKUs and packaging

Currently, the Central Warehouse handles 1947 SKUs. Typology of items can vary, as group units demand goods and consumables regarding 7 different medical specialties. The existing typologies of SKUs are calibrators, laboratory consumables, controls, cleaning equipment, office supplies, reagents and sampling/collection discardable kits.

As for advanced stock, two racks and a designated zone for floored stock hold fifty different SKUs. These specific items represent fifty of the A consumption class composed by 261 SKUs. The results of the ABC analysis based on consumption are represented in the table 2. 43 of the 50 SKUs have small packaging dimensions and each morning, the pickers fill the advanced stock racks with these goods. Therefore, this rack is situated close to the picking table, facilitating retrieval by diminishing traveled distance. As Unilabs operates in the diagnostics branch, units and laboratories have a substantial need for specific tubes and containers. The seven remaining advanced Stock SKUs can not be stored on the same shelves, as the packaging of these items does not have small dimensions, as it can vary from 0,0125 $m^3$ to 0,126$m^3$. Thereby, these group of SKUs, constituted by sample tubes and containers, are floor stocked in a designated space near the picking table.

Table 2: ABC analysis based on consumption

| | % of SKUs | % of Consumption |
|---|---|---|
| A | 13,4% | 80,0% |
| B | 26,4% | 15,0% |
| C | 60,2% | 5,0% |

## 3.2 Infrastructures, layout and equipment

Unilabs currently operates a main warehouse directly linked to the central laboratory located in Porto. Warehousing currently represents 18% of all logistics costs for the company[1]. This infrastructure is responsible for the storage of all clinical analysis consumables, stationary material, and specialized equipment used in medical procedures. Therefore, the space with 220 square meters, figure 5, is composed by a designated reception area, storage units, picking zone and an expedition area directly connected to the exterior parking, where the vehicles that deliver the ordered goods to the care units and laboratories can dock. Currently, these vehicles are responsible for supplying and picking the samples from the care units. In 2019, the company registered an average of thirty delivery vehicles per day, initiating their routes from the laboratory/warehouse facility. This process is later described in the Picking to Dispatch section.

[1] According to the 2018 P&L of the company

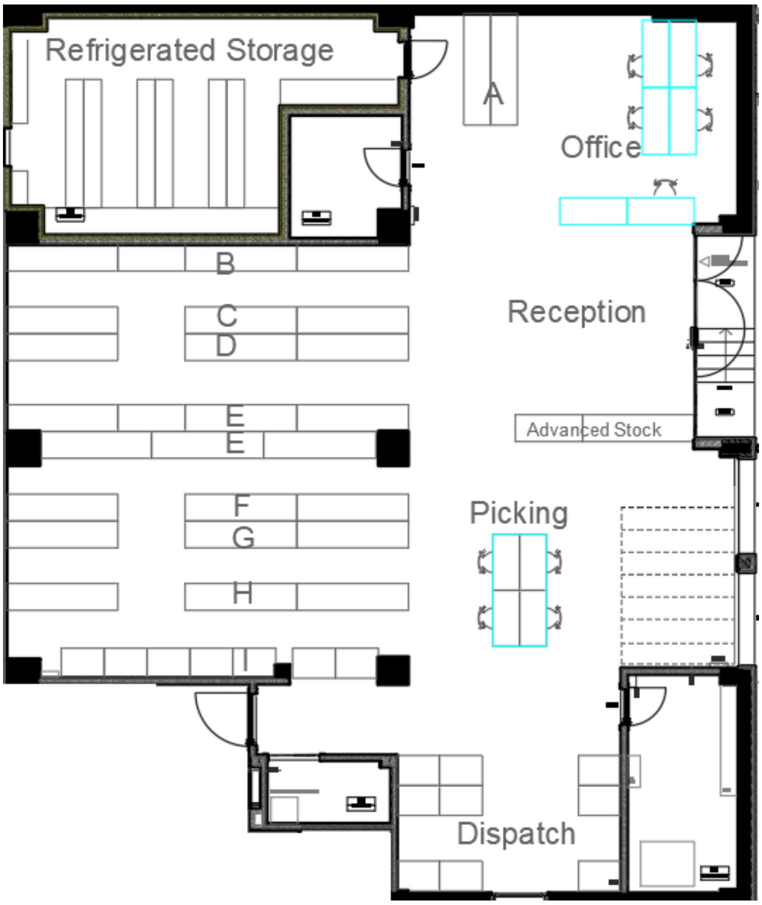


Figure 5: Central Warehouse layout

The reception area represents 17 square meters, and features a designated space to hold the equivalent volume of six pallets. The main activity consists of receiving, registration and verification of incoming goods before storage. This area is located next to the suppliers access and unloading dock. This dock is reserved only for suppliers', as the company vehicles load and unload on a different outdoor location.

$104m^3$ of the space are designated for the storage area. The storage area, figure 6 features 32 rack units with a total of 68 meters of shelving. All shelves have 0,6 meters of depth. Of those 32 units, two of those are located near the picking table, to accommodate an advanced stock. Beyond those two units, 19,25 square meters are reserved for advanced stock on ground for large volumes. As some items require specialized cold storage, $34m^2$ square meters represent the refrigerated storage unit, responsible for storing 800 of the 1947 SKUs. The majority of these items have small dimensions, and do not have a considerable stock quantity. This particular room has an independent access to the laboratory. This specialized storage is currently not working to its full potential as racks are not efficiently positioned and shelving is not fully occupied, leaving 35% storage space inactive.

The picking area is embodied by a 1,4 by 3 meters table where pickers fill the secondary transport boxes with the requested items. This table also has designated areas for small equipment and consumables required for the task, such as scissors, glue tape, permanent markers and other auxiliary office items.

The final stage of the material flow is the expedition area, composed by five rack units. This section is composed of 10,5m $^{3}$ of available storage space. These racks have a considerable vertical distance between shelves in order to accommodate large-sized packages. Table 3 indicates the average size of orders by group.

Table 3: Average order volume by group

| Order size group | volume ($m^3$) |
|---|---|
| Small | 0,0523 |
| Medium | 0,110 |
| Big | 0,321 |
| Total Average | 0,12 |

Next to this area, a passageway connects the warehouse to an outdoor space where the transportation vehicles are parked.

Concerning equipment, the warehouse team utilizes 4 different trolley carts to ease transportation and a manual pallet stacker if suppliers ship materials in large volumes. A two-wheel cart is also available to transport boxes. An office and label printers are also provided to register incoming volumes and items. The information flow is conducted through PHC software where stocks, purchases and requests are all accounted for.


Figure 6: Storage area

Additionally, The company operates a separate warehouse in Fontiscos, located in the area of Santo Tirso. The main purpose of this storage facility is to backup the main warehouse in Porto, which is insufficient in terms of size to accommodate the total safety stock of all SKUs. This backup warehouse also stores furniture and unutilized equipment for medical procedures. By centralizing this type of materials and items, the company was able to reduce the amount of items scattered throughout clinics, labs and units, created an organized inventory and supplies furniture and other specific equipment needed on a temporary basis, while reducing logistics costs. The layout is divided in two distinct zones, next to the entrance 111 square meters of space are equipped with pallet racking. 81 slots for pallets are available in this area to accommodate consumables and medical supplies. Opposite to this zone, a 277 square meters area stores stationary equipment, furniture and medical apparatus. Fontiscos may represent a critical role in the relocation of the main warehouse, as it will be operated as an auxiliary point for material transfer. Figure 7 shows the first storage space of the warehouse located in Fontiscos.

Figure 7: First storage room of warehouse in Fontiscos

## 3.3 Warehouse team

Presently, the warehouse team is composed by eight employees. Three of them are responsible for all the order picking, and are also THE drivers of some care unit routes. Whereas three employees are responsible for receiving incoming goods and store them. The last two FTEs, assisted by the warehouse management software PHC manage stock levels, and assure the replenishment directly with suppliers. The team office space is located in a designated area inside the warehouse.

## 3.4 From Purchase to Reception

As referred in the previous section, the replenishment is part of the warehouse team responsibility. The replenishment has two main processes. SKUs with B, C rotation are ordered whenever the stock level reaches a certain minimum. Regarding SKUs with higher rotation, automatically scheduled orders are requested as consumptions are much more stable.

Suppliers are then responsible to deliver the purchased goods. If the final consumers are units and labs belonging to the central warehouse grid, the goods are delivered on the same centralized warehouse. On the other hand, Pathological anatomy laboratory and peripheral labs and units, have their orders requested by HQ, and have their goods delivered to the nearest warehouses to their location.

## 3.5 From Reception to Storage

When the goods arrive at the warehouse facility through the designated unloading dock, a rigorous chain of action is triggered. The following actions all take place in the reception area. Receiving goods is a delicate moment, which is under the responsibility of the Reception and Storage team. Firstly, a verification must be conducted. This requires to confirm if the items delivered are exactly what was previously ordered. Secondly, quantities must be checked. The expected amount ordered must correspond to the amount delivered and what is registered on the invoice and bill of transport delivered on paper by the driver. In case the amount received does not match with the expected amount, the supplier will receive a warning related to the inconsistency. If everything is in accordance, the team will proceed with the update of the inventory record onto the warehouse management software, PHC. This registration is followed by the printing and tagging of the correspondent label with a different barcode for each item and an internal code number representing the SKU. This identification process of tagging each item of the same SKU demonstrates to be arduous and redundant. As there is no need to know which specific items of the same SKU are consumed or available. The time required to complete this identification process may vary as palletized incoming goods require more time. On average, to print, unwrap the pallet and tag each package, 7 minutes are required. The key information is simply knowing the quantity.

The employee responsible for the receiving the goods, before initiating the put-away activity, must check if any of the goods require refrigerated storage, usually the supplier tags these items with a bright coloured sticker for easy recognition. In this case, the goods will gain storage priority as the quality of the product may depreciate.

However, it was observed that the reception chain of actions does not always proceed with the expected flow and rigor. This is a consequence of two issues. Firstly, the lack of space, due to poor dimensioning, secondly, inadequate process compliance. Secondly, suppliers unscheduled deliveries that promote overloaded moments.

After incoming goods are accounted, the transfer and put away process initiates. The FTEs responsible for this activity, firstly evaluate if the packaging used by the supplier is appropriate for storing the goods as sometimes, repackaging is included in the process. Some SKUs such as flasks and containers are stored inside the supplier's card-boxes, whereas reagents, cultures and other SKUs that require refrigerated storage are removed and stored individually. Goods that require refrigeration, should also be stored or separated in appropriate plastic containers instead of cardboard boxes, as it is cleaner and safer in case of liquid spillage.

As size and typology of goods differ, allocation is based firstly on family grouping. Families are divided by the final consumer. For example, if a specific item is consumed by the Hematology technical department, the rack where it will be stored is distinct from the rack which accommodates sample collection consumables that are distributed to care units. The nine rows of racks, identified with letters, accommodate specific purposed items as shown in the table 4.

Table 4: Warehouse rack rows identification

| Row | Material Family |
|---|---|
| A | Office Supplies |
| B | Core Lab (Clinical Analysis) |
| C | Hematology / Special Biochemistry |
| D | Parasitology / Pre-analytical / Cardiology |
| E | Microbiology |
| F | Pathological Anatomy |
| G | Miscellaneous consumables for care units |
| H | Miscellaneous consumables for care units |
| I | Cleaning equipment |

Within each row, some racks have an increased upright height distance between shelves to accommodate larger sized items. For example, row I, where cleaning equipment is stored, racks have fewer shelves in order to have a greater storage capacity for large items. Whereas in rack E, where microbiology consumables are stored, items have a smaller volume, therefore racks have more shelves and less space in between to accommodate smaller sized items. In terms of area, the storage space for items consumed in the laboratory and the previously mentioned technical departments represent half of the storage space since rows B,C, D, E and cold storage are exclusive to the laboratory supply activity. Items belonging to row A and I are used in the laboratory and also dispatched to units, whereas rows F, G and H as well as floored and advanced stock.

After family-based storage, the following rule is rotation. Higher rotation items (A) are stored closer to the picking table (cross-aisle storage), whereas B and C items are located further away.

Higher rotation items, after being stored in the main racks, also replenish the advanced stock racks, allowing an easier and more efficient picking, as it reduces the distance travelled by pickers. Usually, the advanced stock is replenished once a day, however, a group of five SKUs (Flasks and sample tubes) requires to be replenished twice per day.

Subsequently, the volume and weight are what determines storage after rotation, as heavier products are stored in lower shelves to facilitate picking and maintain a non-hazardous environment. Finally, within each required SKU, FEFO (first-expired, first-out), establishes if the item is picked first. Nevertheless, it was observed that some of the rules and priorities are not followed, as item rotation is no longer a storage policy and items storage slot is not being respected. In the absence of space, items are stored in the nearest space available, compromising storage organisation. An additional problem encountered is the absence of pallet storage. SKUs with higher rotation occupy a great amount of shelving space, creating challenges in maintaining an organised storage activity. Facing these issues will require a thorough study and definition of storage slots, giving special attention to the high rotation and large volume SKUs.

## 3.6 From Picking to Dispatch

Items stored in this warehouse have to main destinations - Care units, and the main laboratory supply, adjacent to the warehouse. The care units order supply is described as following. Order fulfillment starts by a swift analysis and printing of the incoming request. The picker who was randomly assigned to the order, analyses if the type of products and quantities ordered are suitable for the type and size of the unit that placed the order.

The order picking method practiced within the warehouse is pick-by-order, or discrete picking. This straight-forward method prioritizes the order, and demands each picker must visit a picking location individually per each order. This method suits this warehouse as the racks row length and average distance travelled would not bring significant advantages if a batch picking method was applied. The advanced stock, also assists this discrete picking method, as 80% of requested SKUs are stored next to the picking table. Currently, the picking activity (from analyzing until taping the cardboard boxes) takes on average 9:30 minutes. This time was calculated based on a 20 orders sample. However, the sample indicates a standard deviation of 6 minutes, which represents a significant value. On average, orders have 11,47 lines (different SKUs), but a request can range from one to forty different items. Additionally, some SKUs require more picking time, as there may exist the need for counting individual items. For example, needle containers and the appropriate lid are delivered to the warehouse and stored in separate packaging. Therefore, when a unit orders this type of container, the picker counts the exact number of lids to match the container. This process displays an issue as it increases the total picking time. After retrieving items by hand from the shelves and placing them on the picking table, the picker must package all the ordered items with re-utilized boxes. This process also demonstrates some inefficiency, as boxes that used to be the packaging of incoming goods, and are now going to be used as the orders packaging, do not have a specified place to be stored and remain scattered on the floor near to the picking table until its utilization. Illustrated in figure 8. This disorganized accumulation of material, sometimes obstructs passage and hampers the access to the advanced and floored stock, creating difficulties along the picking process.

Figure 8: Disorganized picking area

Finally, the picker annotates on the closed and taped boxes the unit ID that placed the order and the number of the delivery route. All volumes can be placed on five dispatch racks, figure 10, in order to be picked by the correspondent route driver. To ease the process of correct picking identification of the boxes by the drivers, a writing board matrix was developed. Rows list all the routes existing, whereas columns identify the five racks. Therefore, the picker must write the unit ID in the matrix cell correspondent to the rack and the route ID. The dispatch area is also a clear evidence of lack of space. As the 5 racks are not sufficient to accommodate all pending deliveries, resulting in accumulation of packages on the floor creating impediments to the overall flow. The identification process of the correct packages is not straightforward, as it is demonstrated in figure 10. Table 5 shows some key information about the dispatch process.

Table 5: Dispatch statistics

| | |
|---|---|
| Average output per hour | 10 orders |
| Available shelf volume | 6,72 $m^3$ |
| Average order volume | 0,12 $m^3$ |

All delivery routes are composed of a number of care units. The design of these routes was based on location and distances, where each driver, assigned to a delivery vehicle, figure 9, is assigned to one or various routes. This type of vehicle has a volume capacity of 3,8$m^3$. However, the main purpose of these routes is to retrieve the clients' collection samples. Aiding the driver, an algorithm linked with the care units, indicates which care units have samples to be delivered to the laboratory. This is a fragile process, has some samples have short life periods. The supply of goods from the warehouse, takes advantage of these routes. Essentially, when a driver leaves the Laboratory/Warehouse building, he can deliver requested goods to the care unit from which he is picking the samples. This way, the same route can be utilized for two purposes.


Figure 9: Unilabs delivery vehicles

On the other hand, the supply of the central laboratory is currently performed directly by the laboratory technicians. Microbiology, Core, Biochemistry and Hematology departments have a designated technician enters the warehouse and takes the required items directly from the racks that store the laboratory goods (A,B,C,D,E). The process is followed by the tag scan to update the stock. This activity is significantly disorganized as it is unscheduled, as technicians initiate a replenishment activity whenever consumables are required in the technical departments. Quantities picked are not taken into account as there is not a clear analysis of daily consumption, resulting in a disorganized activity that usually takes place several times a day.

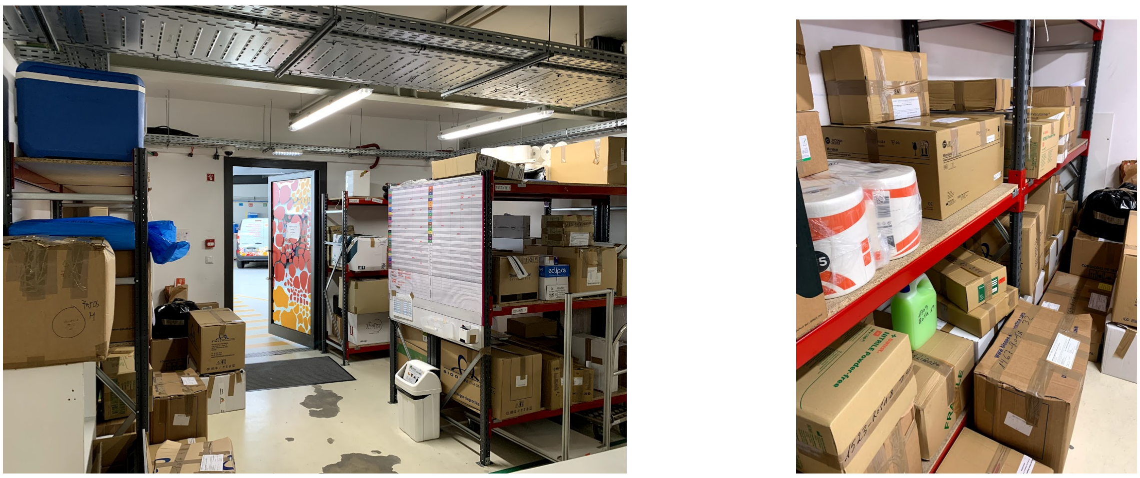

Figure 10: Dispatch Area

# Chapter 4

# Process review and Layout design

The starting point for the process review and the layout design is to define the warehouse's role, throughput requirements, inventory levels and customer service levels. This information was provided by the company, table 6, as it was specified in the warehouse strategy plan, giving this work the opportunity to mainly focusing on the tactical and operational levels.

Table 6: Input data for the Project

| | |
|---|---|
| Orders with at least one missing item | 10% |
| Daily requested orders fulfilment | 100% |
| Unfinished registration of received items per day | 3,5% |
| Maximum Stock for A rotation SKU | 15 days |

## 4.1 Process Design

Alongside the design of the new warehouse layout, the following process review and redesign was conducted. Even though both sections had to be separated to provide an easier organisation of the thesis, it is of major importance to note that, both processes are correlated, and were developed through an iterative operation. The development involved checking back against the system requirements as the design progresses, and assessing the interactions that necessarily occur throughout the process. Finally, in order to gauge how effectively the warehouse operations will meet the future expectations, a warehouse operations assessment was conducted: a systematic review of the warehouse functions looking for possible improvements in efficiency and service.

### 4.1.1 Reception

The reception process was reviewed with the purpose to find *muda* within the workflow. The process was not regularly controlled or evaluated, as KPI's were not clearly defined. As described in chapter 3, priorities were not respected and incoming goods frequently got accumulated due to lack of space and faulty workflow.

A complete flowchart, appendix A, was designed for the department to order tasks sequences and priorities, from the arrival of goods until the appropriate storage. The activity starts when suppliers dock in the warehouse and unload the incoming ordered goods on the correct bay, in the designated spaces for palletized and non-palletized goods. The first task of the warehouse employee is to check if the delivery/shipping note accurately describes the incoming goods, this quick verification must take place before the supplier driver leaves, in order to issue any noticed divergences. It is of extreme importance that the supplier delivers the shipment note, otherwise the warehouse can not receive goods. After the reception, the employee must register the incoming goods on the Warehouse Management System, and verify, aided by the suppliers' tagged labels, if any of the goods delivered requires cold storage, as these items obtain priority and must be stored swiftly. If none of the items unloaded on the reception bay require cold store, the storage process must follow FIFO, first goods received. For each SKU, the staff must then run a detailed and rigorous verification in terms of quantity, reference/model/brand, quality and condition, expiration and lot. If every point is conferred and accurate, the storage activity can take place. However, if the verification concludes any quantity discrepancy, the employee must then rectify the entry registration, concluded upon physical reception and notify the supplier of the issue, in order to reschedule the delivery of missing items. Beyond quantity, reasons for an irregularity can be the absence of some SKU, reception of a non ordered item, lack of satisfactory quality/condition or even the product has already expired. In any of the cases, a replacement must be requested. If the suppliers guarantee a replacement, the process will restart, if not, the company will receive a credit memo. The documentation is available in the WMS through individual *dossier*. This chain of actions was already in action, however, the establishment of a detailed manual shall standardize the work.

### 4.1.2 Storage

The storage process also suffered modifications, as the current storage space demonstrates a clear lack of storage space to hold all SKU in an organised fashion. The new warehouse will continue to have shelved racks, however, new racks capable of storing pallets will accommodate some of the SKUs, classified as A in terms of rotation. This ABC study is described further on the ABC Analysis and pallet storage approach subsection.

When the storage process initiates, after a complete verification of incoming goods, the selected employee must collect the checked items and store them on the correct slots. As described in the proposed layout, the appropriated racks for pallets will have three pallet levels, consequently, the staff will be equipped with a stacker. For non-palletized goods, the correspondent slot will be located on the shelved racks, therefore, for these items, a simple cart can aid the task. The storage process will be aided by the WMS, that after being uploaded the received items data, will assign the SKU to a slot. A subsection will later describe all processes and tasks of the WMS.

The slot assignment rules were modified to be correctly applied to the new infrastructures. Firstly, the two main outbound material flows will continue to be the laboratory and the 620 care units. Even though racks in the current warehouse, separate the two types of goods, the two physical flows ended up entangled, as space was diminished and the laboratory supply activity was not attributed to a certain employee neither was scheduled. For this reason, the new warehouse will have two separate flows, as the SKU slots will be clearly separated, as observed in figure 11.

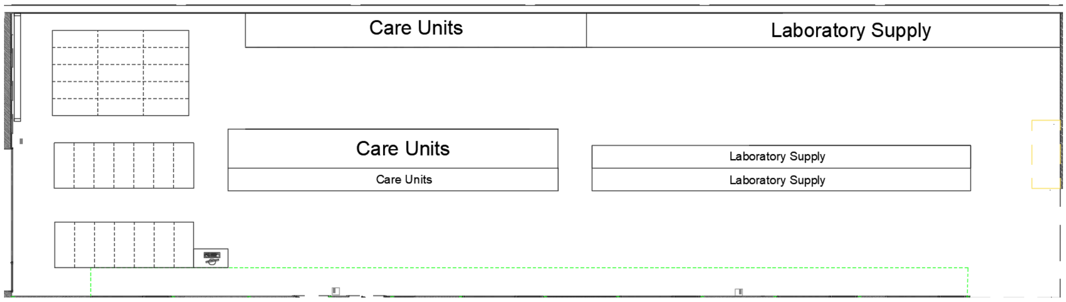


Figure 11: Storage arrangement

Firstly, for the care units supply, SKU are stored respecting this set of rules:

1. Pallet storage/non-pallet storage
2. Rotation (ABC)
3. Weight and volume (shelved racks)
4. FEFO

Whereas, for the laboratory supply, the storage rules are the following:

1. Pallet storage/non-pallet storage
2. Technical department
3. Weight and volume (shelved racks)
4. FEFO

The weight and volume rule, represent a key operational principal, as heavier items should not be stored in the top shelves. Within the SKU slot, the lot must be correctly placed respecting FEFO, this rule will be enforced by placing the older lots next to an acrylic board piece. In other words, the closest item (of the same SKU) on the left side of the acrylic, must be consumed first. This principle will also be applied for cold storage.

### 4.1.3 Picking and Laboratory Supply

#### Picking carts

The picking method chosen will no longer be pick by order (discrete picking), as it is practised in the present warehouse. The new picking method will take advantage of picking carts and the practice of a moving batch picking, where the picker will operate different picking orders in the same milk run. Currently, the network supplies 49 different routes which are provided every day, however it would be extremely inefficient in terms of space usage and logistics to have 49 picking carts, one for each route. Therefore, logistics and the warehouse must work at the same tune in order to provide the exact number of carts required during a specific time frame to supply the demand. The achieved solution for this problem is to divide, by route delivery start time, all orders into four distinct clusters, as it is represented in table 7. Thereby, carts would be available for all picking orders requested for that time frame. This time represents the moment which the correspondent delivery vehicle leaves the warehouse and starts the route.

Table 7: Route delivery start time clusters

| Route delivery start time | number of routes |
|---|---|
| 08:45 - 10:30 | 13 |
| 10:31 - 12:00 | 10 |
| 12:05 - 13:00 | 13 |
| 13:00 - 17:00 | 13 |

By clustering these routes by the start time, the number of picking carts needed for the worst-case scenario is written as described in equation 2.

$$Minimum\ number\ of\ picking\ carts = MaxR \times 2 - AvCartsC \tag{2}$$

where

$MaxR$ : Maximum number of routes in a cluster
$AvCartsC$ : Available carts 1 hour before the Cluster delivery start time

The maximum possible number of routes deliveries in a single cluster is 13. Consequently, the minimum number of carts must represent all previous cluster orders awaiting for the driver and all picking activities in the present cluster have initiated. However, the picking process for one order must start in advance, the logistics and warehousing Departments believe that this activity must initiate one hour before the initial start time of the cluster. Therefore, if we reassign already unloaded carts previous to the start of that one hour, those carts will subtract to total carts required. By achieving the goal using equation 2, the required number would be 24. However, the picking process within each cluster depends on the specific route delivery start time and not only the first of the cluster. This way, an improved calculation was conducted, equation 3. In this case, the some of *AvCarts* would depend on each route delivery start time and not only the first start time of the cluster.

$$Minimum\ number\ of\ picking\ carts = MaxR \times 2 - AvCartsR \tag{3}$$

$MaxR$ : Maximum number of routes in a cluster
$AvCartsR$ : Available carts 1 hour before the Route start time

By exploiting this improved equation, the minimum number of required carts will be 14, as throughout the cluster, carts are unloaded and become available to be reassigned. This calculation was performed in a worst case scenario, where all routes have orders to be fulfilled in a single day.

In order to match the requested order to the cart, the process will also be provided with 98 route coloured identification flags (49 routes plus a copy of each). This way the cart must provide a prop to easily attach and detach the identification flag. The route identification flags will be stored and displayed inside an acrylic structure located next to where empty carts are on hold, providing easy access, organisation and visual control.

Regarding dimensions, orders and dispatched volumes were measured and recorded during a time period of a day.

Table 8: Orders volume by clients per day clusters

| Clients per day | volume ($m^3$) |
|---|---|
| 0-8 | 0,052 |
| 8-15 | 0,11 |
| 15+, | 0,32 |

In addition, the largest recorded order dispatched in the last year occupied 0,65 $m^3$, therefore, it is straightforward, that a cart with the following dimensions: 0,6m x 1,4m x 1m (safe stacking height) is able to hold three picked orders of the first two clusters, and complete a full weekly order on a single milk run, as the volume capacity is 0,74$m^3$. The cart, alike the equipment represented in picture 12, will be equipped with metallic supports to open and hold the three plastic bags, where the picker will place the picked ordered items. Therefore, the picker can pick 3 orders, if possible, of the same route, in one single run, as each bag can hold one order.

Figure 12: Picking cart example

An additional process change was implemented to increase the efficiency of the warehouse and diminish incoming requests. Before, every care unit was able to place one order request per week. However, this resulted in an average of 80 order picking per day. The past warehouse dimensions were extremely inefficient for this workload, especially the reception and dispatch area. It is common to find these two zones overloaded with goods. As all care units belonging to the network are evaluated by the average number of clients per day, it was possible to divide units into three different groups. The company decided, through a logistics study, that care units with less than eight clients per day, may only place an order request monthly. On the other hand, units that fluctuate between eight and fifteen clients will have the possibility to place an order fortnightly. Finally, larger-sized units, fifteen plus clients, will still request goods weekly. By applying this principle, daily incoming orders will be reduced to an average of 50 per day, resulting in fewer but larger incoming orders.

When receiving an order, given by the WMS, the picker must firstly take an empty picking cart and identify it with the correspondent route, this process will be executed by attaching the coloured plastic flag identifying the route number. The cart will be used to perform batch picking, to a maximum of three orders that share the same delivery route, as in a single day, drivers do not attend more than three care units. The algorithm to ensure the picking method will be time window batching. Therefore, the WMS will automatically group care units' orders that belong to the same route and correspond to the same route delivery start time cluster, as one delivery vehicle can transport the goods to a maximum of three units of the same route, due to vehicle space capacity, as it also transports specialized containers to hold collection samples from the care units. In other words, the main objective of this process, is to complete the maximum number of orders of the same route on the same milk run. This calculation will be based on the total volume of items requested. Table 9 represents an array of incoming orders that were delivered at the same route start time cluster.

Table 9: Requested orders example

| Care Unit | Route | Total Volume ($m^3$) |
|---|---|---|
| 1008 | 38 | 0,104 |
| 2319 | 6 | 0,500 |
| 2004 | 38 | 0,221 |
| 1645 | 14 | 0,400 |
| 1001 | 14 | 0,243 |
| 2201 | 38 | 0,074 |
| 1302 | 14 | 0,130 |

Giving this example, the WMS will create the following four batches described in table 10.

Essentially, the software will group all three orders of route 38 as they do not exceed the maximum volume. Whereas, route 14 could not group all 3 orders as the total volume would exceed the volume capacity of the designed picking cart in subsection Picking Carts, 0,74$m^3$. Each order will be assigned to one or more bags if the order volume requires than one plastic bag. Plastics bags, would be a better solution not only to the clients but also to the warehouse has the size is standard and have flexible storage capacity. For example, in the present warehouse, the process of choosing the right box for the order size takes some time. Furthermore, an adequate box may not be available, therefore the picker must use an oversized box occupying valuable space. Consequently, the picking activity may initiate. The WMS will analyse the requested items

Table 10: Created batches from orders example

| Batch Route | Care Unit | Total Volume ($m^3$) |
|---|---|---|
| Route 38 | 1008<br>2004<br>2201 | 0,399 |
| Route 14 | 1645<br>1001 | 0,643 |
| Route 6 | 2319 | 0,220 |
| Route 14 | 1302 | 0,130 |

and indicate their location on the PDA, therefore, it will ensure a swift activity and the minimum distance covered. After completing the assigned orders, the picker must place the cart on the full carts holding slots, as it will await the driver of the corresponding route to load the delivery vehicle. As the majority of heavier and larger items are palletized, these items will also be picked first as the picking route initiates in the aisle where all palletized items are held. As described in the Layout section, the warehouse will be divided into two different zones, thus the picking flow will only operate as described in figure 13.

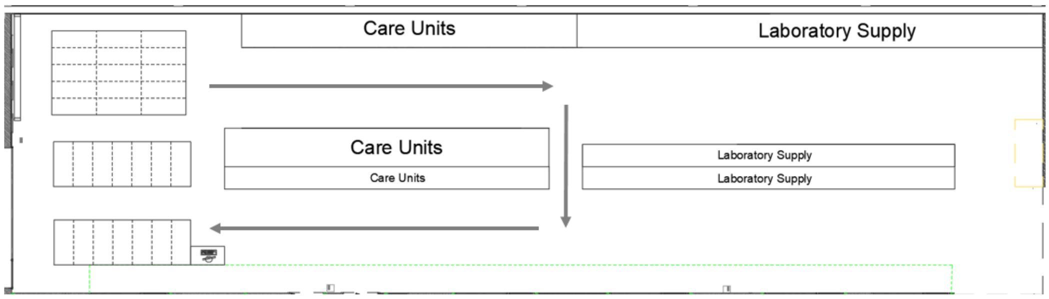


Figure 13: Care units picking flow

It is possible to observe that the main picking flow will take advantage of the shortcut as care unit items are grouped together on the left side of the storage area.

### Laboratory supply

The laboratory supply represents a different picking process. As described in chapter 3, this disorganized supply was supported by the technical departments technicians. As SKUs are dissimilar and stored separately, the picking process is independent and will not affect the care unit picking activity. In this case, a designated member of the reception team, as they presently have a deep knowledge about these SKUs, will supply all advanced storage units located in the following technical departments as referred in table 11. the laboratory will also suffer improvements, a new technical department will be added, Pathological Anatomy. If the activity is under the reception team responsibility, the warehouse access will be positively restrained. Nowadays, this process takes on average 7:25 minutes, picking and delivery time included.

As referred in the previous subchapter, the SKUs are stored by the technical department to facilitate the picking activity. This activity will be aided by simple two picking carts, represented in figure 26 in the equipment section, that already were utilised in the previous warehouse. The quantities will depend on the dimensioning of the advanced storage of each department. The activity shall take place once per day, two technical departments will be supplied at the beginning of the day, before the supliers schedule begins, and three remaining departments will be supplied during the end of the afternoon for the same reason. Only a maximum of two FTEs of the reception team can perform this activity at the same time so the warehouse reception does not become unassisted. The main focus is to avoid creating disturbances to the care units picking. The flow is described in figure 14. It is expected that this supply process requires more time as the expansion of the laboratory and warehouse facilities will increase the total distance travelled. Despite that increment, this activity does not represent a resource problem, but a organisation and structure problem, has it led to the entering in the warehouse of non-warehouse employees.

As referred in chapter 3, the laboratory technicians, are responsible for this action and did not execute a scheduled and organized replenishment procedure. This replenishment may happen several times a day, as quantities are not daily oriented. With the upcoming expansion of the laboratory that will accompany the new warehouse design, these technical areas will be provided with advanced stock facilities that can be refrigerated if required, opening up the opportunity to create daily scheduled resupplies for these departments under the responsibility of the warehouse team.

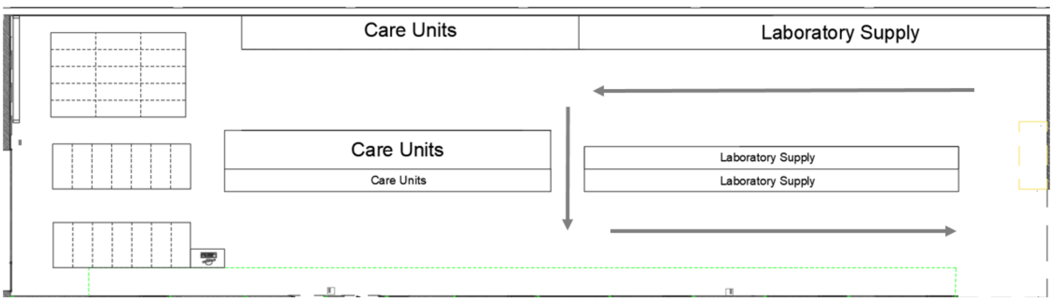


Figure 14: Laboratory Supply picking flow

Table 11: Technical departments supply

| Technical department |
|---|
| Microbiology |
| Core (Clinical Analysis) |
| Biochemestry |
| Hematology |
| Pathological Anatomy |

**Pallet transfer**

When a picker does not have the required quantity in the floored pallet, a signal is sent to the Warehouse Management team in order to transfer a pallet of the same SKU from the top levels with the stacker. This equipment is later described in the equipment subsection. This activity is under the responsibility of the reception team.

### 4.1.4 Dispatch

After finishing picking the order, the picker must park the picking cart on the dispatch bay. Afterwards, the shipping invoice must be printed using the printing equipment next to the full carts slots. Finally, the driver, after parking his vehicle, can access the dispatch bay and identify the correct cart for his driving route. As all carts are identified with a designated plastic flag, which turns the identification process into a straightforward task. Secondly, the driver can grab the cart and load his delivery vehicle with the picked goods. Finally, the picking cart must be parked on the designated location and have the route flag removed and stored on the acrylic display, so the picking activity may restart.

### 4.1.5 Team Dimensioning

To calculate the number of FTEs required for the picking activity, the process had to be simulated. Firstly, an average number of lines by order was calculated. The sample was composed by a full day of orders. On average, each order has eleven different SKUs. Additionally, a SKU picking that requires counting large quantities takes more time. This way, it was measured that all picks that require counting more than 50 items will take 210 seconds. The inputs are represented in table 12.

Table 12: Inputs for full picking time in seconds

| Input | Value |
|---|---|
| Grab picking Cart | 8 |
| Stop Movement | 2 |
| Initiate Movement | 2 |
| Simple picking | 5 |
| Picking quantities over 50 units | 210 |
| Cart parking | 8 |

By using the proposed layout, it was possible to calculate a full order picking time. By simulated picking, random order lines were given and the total average distance was calculated in table 13. The productivity was an input value to this project.

Finally, the results are presented in table 14.

Using this scenario, one FTE would be able to complete all requested orders as the total working time is 7:30 hours if we remove one hour for lunch and 30 minutes for breaks.

Table 13: Average distance travelled and time spent

| | Value | Units |
|---|---|---|
| Productivity | 90% | |
| Average human Speed with cart | 1,1 | m/s |
| Time spent moving | 36 | s |
| Average distance | 39,6 | m |

However, the time span to complete orders is not a full working day. As orders are clustered by routes, the cart needs to be ready with all ordered goods before the route start time. Therefore, if the maximum number of routes per cluster is 13, that number is the minimum number of milk runs to complete in one cluster. The cluster selected for this calculation is represented by the following time span, 12:05 to 13:00. Route clusters are exhibit in table 7.

$$Required\ Pickers = \frac{6,75\ min \times 13\ orders}{55\ minutes} = 1,6\ pickers$$

Supporting a decision on these calculations, the activity will require 2 FTEs. As for the reception team, in the current warehouse, three FTE are responsible for receiving and storing the incoming goods. The designed warehouse will maintain the same employees. This decision is based on the fact that at least two employees must undergo through a forklift operation training in order to perform machine aided storage.

## 4.2 Layout design procedure

The starting point for warehouse design is to define the warehouse's role, throughput requirements, inventory levels and customer service levels. This information was provided by the company, as it was specified in the warehouse strategy plan, giving this work the opportunity to mainly focusing on the tactical and operational levels.

After receiving this data as the foundation of the project, the first step was to observe and study the space available. The new warehouse will be located next to the laboratory building in Porto. By spending some time on this initial step, it was possible to slowly perceive the spacial organization of the core flows within the warehouse. Reception, replenishment, picking routes and dispatch, taking into account the internal and external space and layout. These flows were later tuned by clearly defined ABC items location and particular storage units such as refrigerated products.

The appropriate equipment and operating methods were also determined through appropriate calculations, due to the previously mentioned problems in chapter 3. Therefore the future warehouse must be able to accommodate the adequate workforce for the required duty.

After the planning base was formulated, the overall project was evaluated in terms of storage capacity, movement distance, rotation ratio and points of congestion. This assessment, by running

Table 14: Inputs for full picking time

| Result | Value | Unit |
|---|---|---|
| Average Picking Time | 405 | s |
| Average Picking Time | 6:45 | m |
| Average number of orders per day | 50 | |
| Daily time spent picking | 5:37 | h |

concept trials, gave the opportunity to carefully adjust several crucial points in order to create and maintain a clear flow throughout the process.

The primary objective of the layout design was to maximize the functional space and storage capacity. Image 15 was provided as an input and displays the available space.

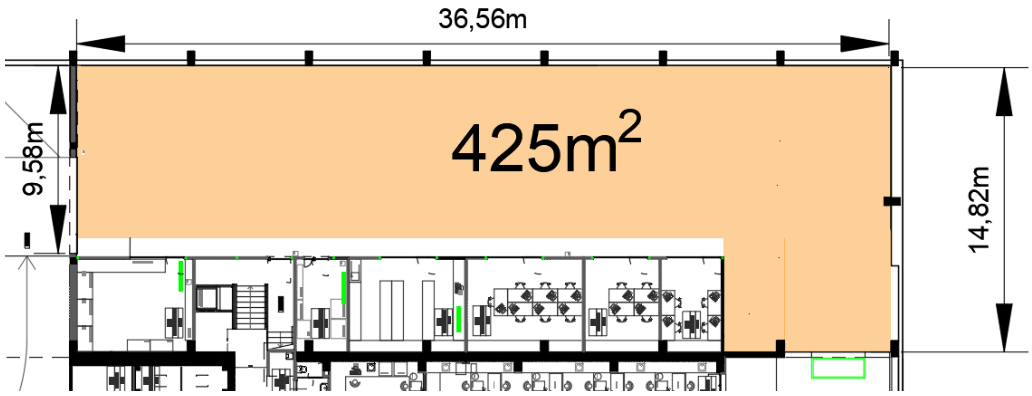


Figure 15: Warehouse floor area

The image represents the available floor area for the project. The highlighted area with a floor space of 425m$^2$, represents the layout available for the following actions: reception, storage, picking and dispatch. This space represents an increment of 93% when compared to the previous warehouse. To conclude, the shape of the available space was carefully taken into consideration, so the design would achieve maximum storage capacity and clear flow channels.

The warehouse can be accessed through three different ways. The first entry, represented on the right part of the blueprint will be for motorized access only. Equipped with a loading platform to compensate for the height difference of 2 meters between the warehouse floor and the driveway, it will operate has a loading dock and provide the entrance for incoming goods. It will facilitate access to suppliers' semi-trailer trucks and smaller delivery vehicles and the respective unloading process. The reception area will be placed right next to this entrance in order to facilitate the operation flow. The second entry, is for pedestrians only, and will provide a connection between the warehouse and the laboratory. Finally, the dispatch process will occur on the left side of the blueprint. The route drivers will be able to park the delivery vehicles in a designated space next to the entrance, for a brief moment to ease the loading process of the ordered items. A one-meter width hallway, represents a restriction, as six offices are not linked directly with the laboratory, therefore this hallway will be utilized as a pedestrian passage. The developed and proposed layout is represented in figure 16.

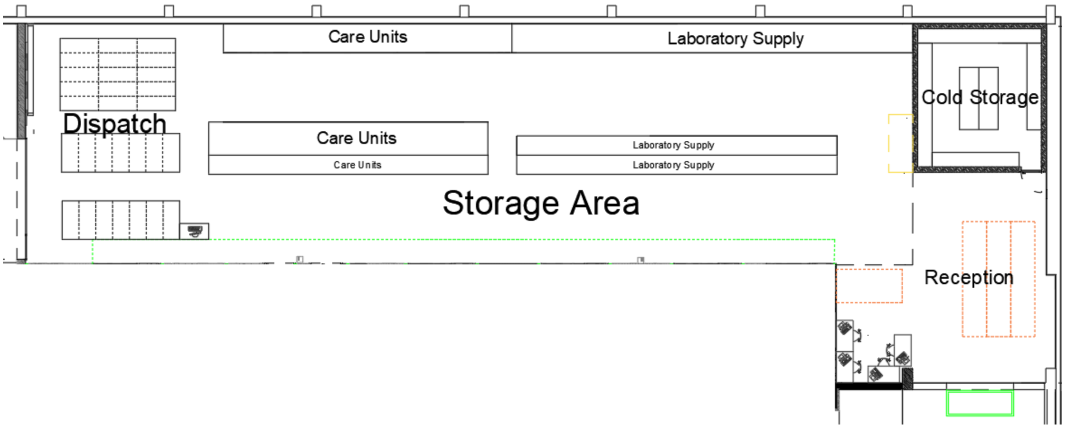


Figure 16: Warehouse layout

### 4.2.1 Reception

As cited by Rushton (2010), activities listed under reception and dispatch should represent an area of 20 to 30 percent of the total floor area to facilitate the efficient flow of goods into and out of the warehouse, therefore the sum of reception and dispatch is estimated to occupy between 85 to 127m$^2$. As referred before, the reception will take place after the right entrance. After pallets and smaller delivered packages are unloaded from the vehicle, and placed on the loading platform, a designated space right after the entrance will provide sufficient room to receive the goods and initiate the described reception process in the process review chapter. This area shall accommodate twelve pallets occupying 12m$^2$, representing a capacity increment of 100%, plus 30m$^2$ of free space around to enable equipment movement between pallets slots. The activity in the current warehouse demanded more space for unloading palletized goods as the largest regular delivery accounts 10 pallets. This way, an available space for twelve pallets shall easily deal with the current and future growths. The space will also be equipped with a 3.8 m$^2$ table to hold non-palletized incoming goods. Finally, 9m$^2$ will be reserved for the warehouse team desk workspace. In total, the reception zone will occupy 55m$^2$ enabling a clear physical flow towards the storage units. This sector will also provide access to the cold storage facility.

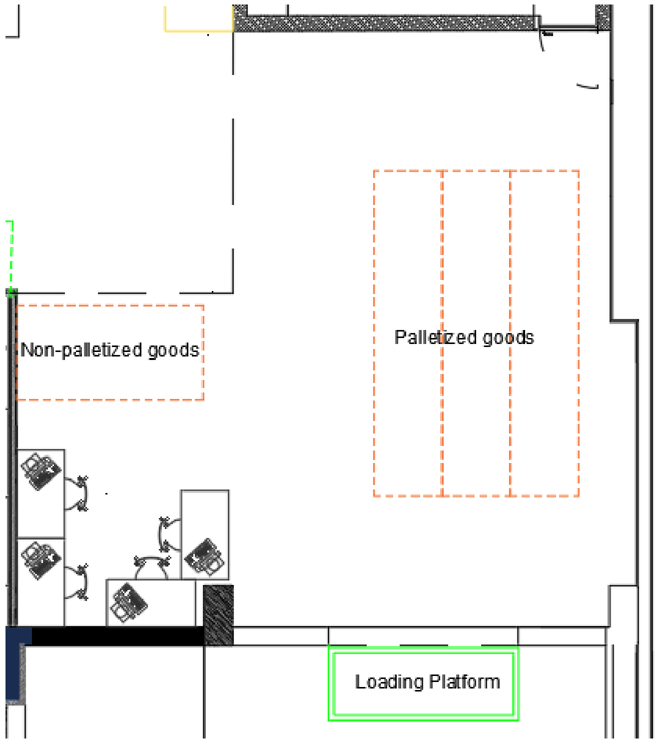


Figure 17: Reception area

### 4.2.2 Storage and picking area

The main principle of the warehouse was not to maximize total storage capacity at all costs. The target of this layout was to establish an organised facility, that promoted this new dynamic picking method and facilitated the replenishment of the laboratory technical departments. Therefore, by taking advantage of the shape of the available space, it was created a clear and simple flow for incoming goods and for throughput. One input given by the company was to implement pallet storage, to facilitate storage in greater volumes. Therefore, wider aisles were required due to the utilisation of storage equipment such as a forklift or a stacker. One key objective of this new warehouse is to clearly differentiate high rotation SKUs (Class A) and apply appropriate pallet storage, tackling two of the major problems in the present warehouse, slots organisation and space available.

The storage area will have two main aisles, each measuring 2,78 meters in width. This width is compatible with the chosen equipment, as referred later, in the equipment subsection. The first aisle, will provide access to two types of storage. The storage units next to the back wall, measuring 27 meters, will be pallet holding racks as represented in the Appendix B.1. Each rack unit, measuring 2,7 meters in width, unit can accommodate 3 euro-pallets (0,8m*1,2m), with 1,5m of height. Each rack will have three vertical levels, resulting in a capacity to hold nine pallets. The storage units in the middle of the layout, will be composed by four pallet holding racks (10,8m) plus 13 meters of regular shelf racks B.2. Finally, the second aisle, provides access to 25 meters long of shelf racks. In total, the storage facility can accommodate 126 pallets, of which, 42 are floored, meaning that 42 different SKUs can be stored. A corridor will pass through the middle storage units to facilitate access between the two main aisles. Additionally to the care units, the warehouse also supplies the connected laboratory. Therefore the storage facility will sustain two main physical flows as it is described in the Process design section. The physical requirement of these two flows will divide the racks as it can be observed in figure 18. The division was based on the required storage capacity for each process. This layout took into consideration the consumption analysis described in the next section.

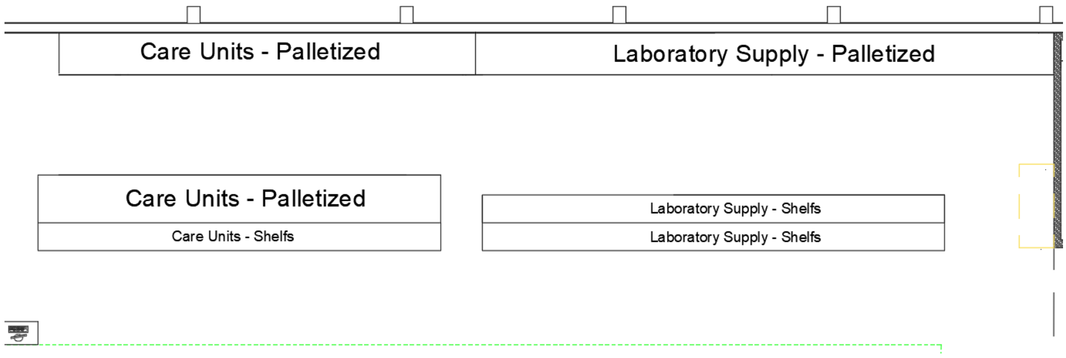


Figure 18: Storage arrangement

Care unit SKUs are held closer to the left side of the building, diminishing the picking travelled distance, as the start and end of the activity takes place on the left part of the blueprint. Whereas Laboratory Supplies do not require that level of performance, as the activity will only take place once per day, as described in the process review section. In figure 18 a dedicated space on the right part of the blueprint, was applied to the park the stacker.

**ABC Analysis and pallet storage approach**

As previously palletized storage was not used, an ABC consumption frequency analysis, was conducted to all 1947 SKUs, in order to identify the higher rotation/class A SKUs that could use pallet storage. The chosen SKUs were not only based on consumption rotation but also supported by the fact that the majority of this item, is already delivered in pallets. Table 15 describes the results.

Table 15: ABC Analysis based on consumption

| | % of SKUs | % of Consumption |
|---|---|---|
| A | 13,4% | 80,0% |
| B | 26,4% | 15,0% |
| C | 60,2% | 5,0% |

The class A accounted for 260 different SKUs, and represented the "candidates" for pallet storage. Pallet storage for items belonging to B and C classes would not be beneficial as consumption is not substantial. After focusing only on A-class SKUs, consumption was listed and a 15-day stock was calculated. This is the current time span stock for high rotation items practised by the company. Consumption volumes were also required to the analysis, therefore clusters of similar-sized SKUs were created to ease the registration of all volumes, as the company does not keep a size database. By multiplying the consumption volume with the required stock for fifteen days, it was possible to analyse which item storage space occupied a significant volume for pallet storage. This process was executed two times, for Care units and for Laboratory Supply. Regarding Care Units, fifteen SKUs demand a storage space of more than one pallet. Additionally, eight more SKUs have a high consumption volume that almost occupies one pallet, therefore this specific SKUs will also be stored in pallets, totalling twenty three required pallets. Concerning the laboratory supply, a total of fifteen SKUs will demand palletized storage. In total, the network consumption will require 38 different pallet floored slots. In conclusion, High rotation, A class SKUs will occupy 46 (Care units) plus 17 (Laboratory), totaling 63 pallets of 126 available. This calculation rounded a 15-day consumption volumes to multiples of a pallet storage space, 1,44$m^3$. In conclusion, this available space will provide accommodation for future growth as the company registers a 5% organic annual growth in consumption.

### Shelf rack SKUs

In order to calculate the remaining space required, two distinct methods were conceivable. The first would rely on grouping the remaining 1109 SKUs, as of the 1947 SKUs, 38 are A-class items stored in pallets and 800 are refrigerated. This grouping process would be based on typology, and each group would be attributed with representative dimensions and volume. However, even for items that belong to the same product family, the range of volumes is immense, therefore, the groups created would not represent correctly the volume occupied. For example, within the Microbiology typology, the following SKU, Reagent Diluent Cellpack DCL, has a individual volume of 0,026 $m^3$. Whereas Cellclean Auto (20x4ml), only occupies 0,0005$m^3$. Another major issue of this method would be the number of stock days attributed. Presently, there is not a common rule of stock days applied to goods. Each SKUs is delivered and stored in different quantities. Occasionally, the holding quantity of the same SKU may vary throughout the year.

Thereby, the second method would demonstrate to be a closer and finer representation of the warehouse requirements. This method consisted in calculating the total storage capacity, including floored stock, of the present warehouse and subtract the volume of A-rotation SKUs, chosen to be palletized, for 15 days of stock. The result represents the total volume needed for the 1109 SKUs, for the practiced stock days. This process was performed separately for the first time for the Care units SKUs and Laboratory supply. The results are presented in table 16. The required volume quantity was achieved by performing the second method previously explained, whereas, the available volume is the storage space in the new warehouse available for the same SKUs. The overall layout and storage arrangement can be observed in figure 19.

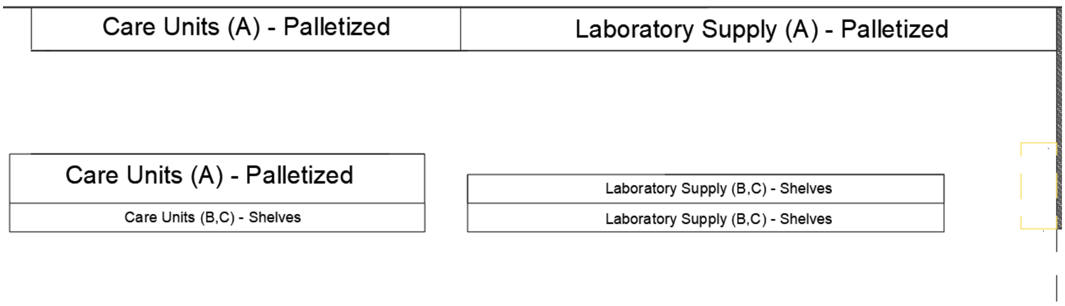


Figure 19: Storage arrangement by ABC

Table 16: Required and available storage volume in the proposed warehouse

| | Care units | Laboratory |
|---|---|---|
| Required ($m^3$) | 18,01 | 40,37 |
| Available ($m^3$) | 19,00 | 45,76 |

Table 16 clearly demonstrates that this shelf units can accommodate present and projected needs for at least two years with a 5% annual organic growth of consumptions. After the next three years, some stored shelved SKUs can have start to be stored on palletized racks, as this storage method has more empty space, will have 63 slots available. Another possibility would be to expand this shelved storage units and create a new row, located against the empty hallway.

#### 4.2.2.1 Refrigerated Storage

As referred in the previous chapter, all 800 SKUs that require cold storage, only supply the laboratory, they are not dispatched to care units. Despite representing 41% of all stored SKUs, the majority of this items have low rotation and significantly small volumes.

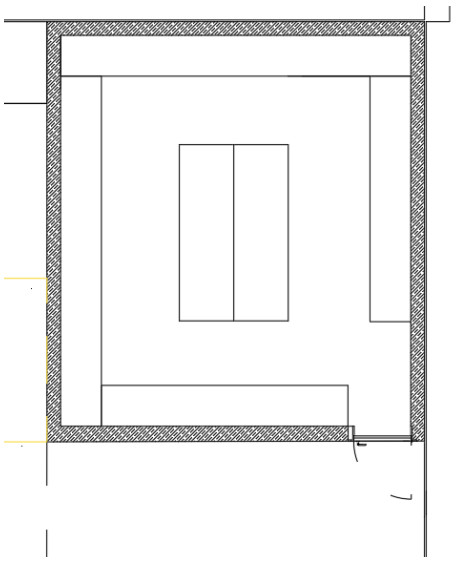

Figure 20: Refrigerated Storage layout

The future growth of the Laboratory will not involve a required increase of the refrigerated storage area. This specialized zone will have the same $34m^2$ has the previous warehouse. The final layout of this storage facility is demonstrated in figure 21. Despite the new medical technical department transferred to the future building, currently located in other laboratories, this departments will be equipped with their own refrigerators. Therefore, as the current cold storage is underutilized, 35% of storage space available, the effective storage area will remain the same size. As the majority of cold storage SKUs have small dimensions, the original cardboard packaging will be substituted by a specific plastic storage container, ideal for small items, as represented in figure 20. The reception area creates access to this facility.

Figure 21: Plastic picking box for refrigerated storage

Each container could hold more than one SKU, as some reagents are dependent from others when being applied. Another example of batch storage are *Immunocap* Allergenic shots represented in picture 22. Accounting for 195 SKUs, as each represents a different allergy, this items are usually stored together.

Figure 22: Immunocap Allergenic Tests

### 4.2.3 Dispatch area

The following sector will operate three connected tasks. Firstly, it has to briefly accommodate a maximum of fourteen carts packed with orders awaiting the route driver, figure 23. Secondly, it must have a designated space to hold the empty carts on standby after the loading process of goods into the route vehicle. The dispatch section will operate right before the exit on the left side of the blueprint, establishing a fast and efficient dispatching process. As the carts will approximately occupy 0,90m$^2$ of floor area, taking into account 5cm between each cart as clearance space, 16m$^2$ will be effective holding space. To ease access and improve the flow of the process, corridor must remain clear between the holding slots, and empty space around the slots, totalling 22m$^2$.

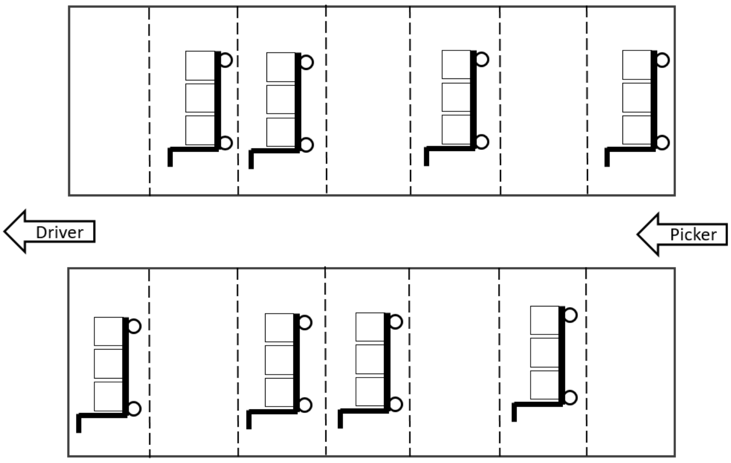


Figure 23: Holding slots for full carts

In addition, the empty carts slots do not require the same level of accessibility. The empty carts are driven through one side of the slots, pushing towards the pickers the upfront carts, as demonstrated in figure 24. This flow ensures a simple and efficient way of slotting the equipment. The following space requires 14m$^2$ of holding area, plus 15m$^2$ of empty space around.

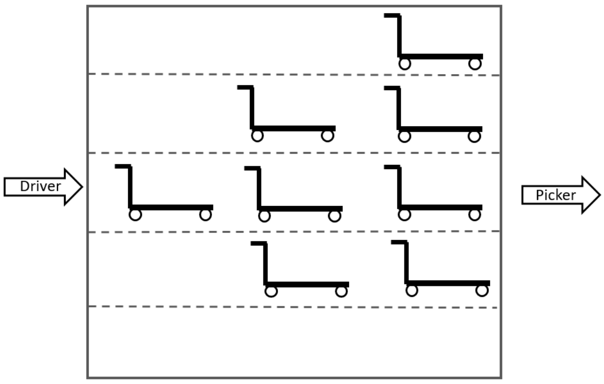


Figure 24: Holding slots for empty carts

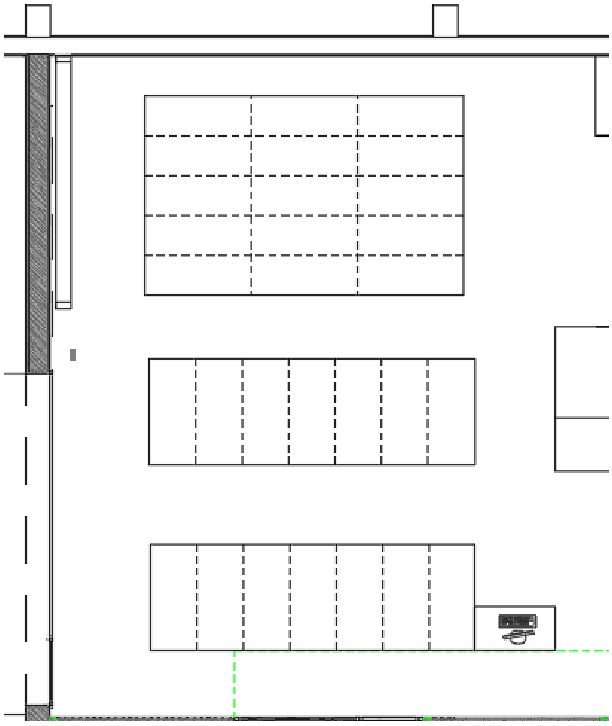

Figure 25: Dispatch area layout

This dynamic process removes completely the necessity of shelving for dispatch which in the old warehouse was one of the most substantial contributors regarding poor efficiency, as it created a bottleneck right by the exit of the warehouse, as drivers consume considerable time finding the correct packages scattered on the shelves. The cart identification process will be aided by the coloured identification flags, creating a easier process when compared to the present one.

Accounting for all space, the dispatch area, figure 25, will occupy 68m$^2$. The area must be kept empty and clean to ease the process flow, as the left exit and some space around the acrylic support to hold the identification flags. Adding this space to the 48m$^2$ of required reception area, both zones will account for 116m$^2$, respecting Rushton (2010) rule of thumb.

### 4.2.4 Equipment

#### Stacker

This equipment, figure 26, was chosen due to its capacity to operate in narrow aisles. Table 17 exhibits the main technical data of the selected equipment. This equipment will have a designated parking space between the storage and reception area, as demonstrated in figure 18.

Table 17: Stacker technical data

| | |
|---|---|
| Cargo capacity | 1,2 tons |
| Lift capacity | 4 m |
| Minimum aisle widht | 2,3 m |
| Turning radius | 1,6 m |


Figure 26: Chosen stacker model

**Pallet trolley and Transport carts**

This equipment will aid several activities within the warehouse. Firstly, the pallet trolley, figure 26, will aid the unloading process from the supplier truck onto the loading platform and to the reception area. Whereas the three transport carts, figure 26, will support two activities. Firstly the replenishment of items that do not arrive palletized. The responsible employee will use the cart to transport the incoming goods, from the reception zone to the correct storage slot. Secondly, this equipment will be used in the picking process to replenish the laboratory technical departments.

Figure 27: Transport cart and pallet trolley

### 4.2.5 Information flow and warehouse management software

The goal of this subsection is to identify all processes operated by the WMS that enables to create a efficient flow throughout all the warehousing activities.

- Clustering incoming orders: This operation is already in action in the current warehouse warehouse. Even though care units do not have a date/time restriction to request goods, the system manages to distribute these orders throughout the working days of the week to stabilize the workload. Moreover, the system also tries to group the requests by routes. Culminating in clusters of orders of the same route, which means a common route delivery start time. This operation will enable an organised and simple picking activity.

- Picking batch arrangement: After organising incoming orders by clusters, the system will be capable as referred before to create picking batches. The orders are already organised by route, but a picking cart is not designed to hold more than three orders. Therefore, the WMS will agglomerate picking batches that the total volume request does not exceed 0,74m$^3$, the cart maximum capacity. The system will require and data input of the SKU requested unit volumes.

- SKU location database: To guide the picking activity, the WMS must recognize the SKU ordered and lead the picker to the correct slot, where the item is stored. A continuous update on the input data is required, to register new SKU or simply change a common SKU storage slot. This database will enable the WMS to guide the picker to the closest next picking line item.

- Inventory update (barcode scanning): In order to amke the inventory update process leaner, units of consumption will be reduced to the possible minimum. For example, the consumption unit of needles was a whole 100 units box. If a picking line only required 10 needles, the picker must read the box barcode and the system would remove 100 needles from stock. Everytime a new box is opened, the process repeats itself. The purposed process to reduce consumption units would efficiently work with the aid of the WMS. Equipped with the PDA, the picker will read the barcode and choose the exact quantity of items required. This way, the arduous process of labeling each item with a barcode can be discontinue, saving time.

### 4.2.6 KPIs

In order to better track the future performance of the warehouse, KPIs were established:

- productivity (receive per man-hour) for receiving
- cycle time for order picking
- Over-storage by SKU
- Orders with at least one missing item
- Daily requested orders fulfilment
- Unfinished registration of received items per day
- SKU shortage

By keeping an continuous improvement mentality, the warehousing department can secure a favorable warehouse performance, by employing the established KPIs.

# Chapter 5

# Conclusion and Future work

The developed project focused on designing a new warehouse layout and the reshaping of the warehousing activities and flows in a clinical diagnostics company central warehouse. This improvement would address the rapid growth of the network in Portugal, as the current warehouse is not able to cope with demand. A 220m$^2$ facility represents the central Headquarters to a complex network with 620 Care Units and laboratories. The current situation was not ideal, as the standards began to drop due to lack of space and organization, outdated equipment, non-optimized processes, and a lack of responsibility and task assignment. The current status of the warehousing circumstance guided the main objective of this project, to re-dimension the facility in a new empty space and adapt the current processes to the new infrastructure.

The project started with an analysis of the current operations and activities. The initial objective was based on the lean principle of addressing "Muda", and remove it from the process. This analysis was performed for the four main warehouse activities. The reception of goods was the activity that suffered fewer alterations, has the only modifications were related to rules and priorities. The remaining three activities suffered a complete restructure as the methods were transformed completely. The improved reception activity will start in the current warehouse. A thorough analysis was conducted to evaluate the 425m$^2$ of available space maintaining Flow as the main principle. The designed warehouse was structured to provide a clean flow through all activities, not only inside each of them but also between. Incoming goods enter by the right side, whereas the dispatch is on the left, establishing a clean physical flow to avoid crossing and conflicts. Within the reception area, the pallet receiving capacity was duplicated. This increment of space will help the warehouse to achieve the goal of 3,5% of unfinished registration of received items (per day) as it will allow performing the activities in the adequate free space, which will decrease the time required to perform the activity. All distinct areas were designed to properly adapt the warehouse to the customer network requirements. The main storage area suffered a complete restructuring, with the implementation of pallet storage equipment, increasing storage productivity, processes and priorities had to change. The order picking activity was also completely redesigned. The new moving batch picking was a creative idea to maintain a robust but simple flow along with the activity. When comparing to the previous warehouse, it creates the possibility of picking a maximum of 3 orders on a single milk run, whereas the previous method, order picking limited a FTE to a single order. The achievement of 100% of daily fulfilled orders will benefit, as the redesigned activity is expected to decrease the time to complete a picking run by 29%. This improvement becomes even more evident has a single picking run in the new warehouse can fulfill a maximum of three orders. The additional work towards restricting incoming orders will reveal itself as a key factor for the new processes. By time-restricting the care unit orders by size, the number of incoming orders will reduce from an average of 80 to 50 orders per day. This decrease will favor the dispatch process, as the number of orders on hold waiting to be dispatched will reduce significantly.

In the end, the future proposed warehouse will serve as the headquarters to a complex network by providing a suitable space to perform the redesigned activities that were already established in the current warehouse and providing capacity for the 5% annual organic growth in consumption.

## 5.1 Future Works

Continuous improvement is an ongoing process that stimulates the permanent aim to keep improving service level by increasing efficiency and reducing warehousing costs. In the short term, some preparations may be taken, so when the proper facility construction initiates everything goes according to the plan. It is of extreme importance that the Warehouse and Procurement department create a database with all consumption volumes of each SKU. Firstly, this information is crucial for the WMS. If one of the main goals of this dissertation is to let the system coordinate batch sizes and slots required, this volumes database must be kept updated. A procedure to easily start collecting this information is to retrieve the volumes/size data directly with the supplier instead of measuring every single unit. Adjacent to this accumulation of data, the Warehousing department should also clearly reduce the consumption units to the minimum to all SKUs. This would simplify the picking activity and is crucial to the inventory update task. An accurate and simple database would be a vital tool for further development and expansion. After activity in the new warehouse has started, previously defined KPI's will evaluate the new warehouse processes performance.

In the long term, the Procurement team should target a greater supply chain upwards information exchange and control, in order to demand more rigorous delivery time from the suppliers. An uncontrolled reception process could form a bottleneck and disrupt the warehouse flow.

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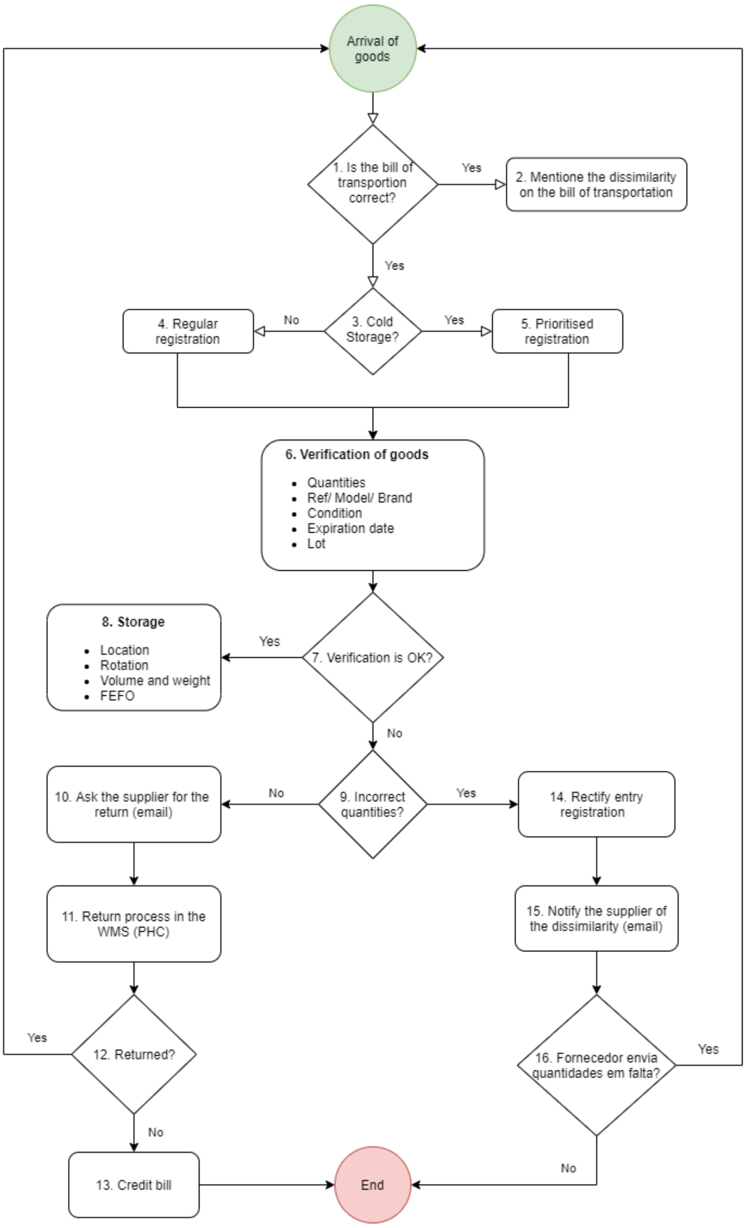
# Appendix A

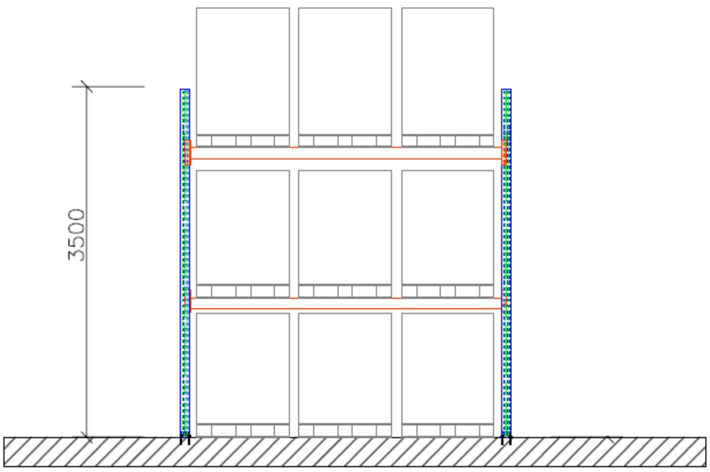
# Reception and Storage Flowchart



# Appendix B

# Storage Solutions

## B.1 Palletized Rack




## B.2 Regular Shelf Rack