Study of Storage Allocation Strategies and their Application to a Logistics Service Provider

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“We keep moving forward, opening up new doors and doing new things, because we're curious… and curiosity keeps leading us down new paths."

Walt Disney

Abstract

This project was developed in the company Rangel Distribuição e Logística with the goal of improving the product allocation strategy in its warehouses. This involves the creation of an ADE, Alocação Dinâmica de Espaços, (Dynamic Storage Allocation) model that aims to optimize the receiving and put-away processes with the support of a Warehouse Management System (WMS). This project is intended to help future programming of the system to make it automatically suggest the optimal storage location of the pallets received in the warehouse. This model encompasses inbound and outbound operations with the objective of optimizing them, that is, working towards the reduction of their cycle times and, consequently, their costs for the company.

Thus, throughout this work, several strategies and methods were studied based on the literature as well as on the three companies visited: Bosch, Aapico, and Parfois. It was possible to verify that the three companies studied use the chaotic allocation strategy with some specific characteristics adapted to each of their warehouse's realities. In addition, they have layouts that are highly sectioned by customers and customer families, which is an added value in reducing picking times. Finally, it was verified that Parfois has a very interesting storage system that gives priority to the storage places closest to picking places of the SKU in question.

Based on all the information studied, it was possible to create a model in the form of a flowchart that encompasses several strategies that were thought to be relevant to the reality of Rangel. Thus, after a detailed study and several team decisions, it was decided to idealize a strategy based on classes, which can be adapted for each warehouse and each case. Thus, if in a given warehouse, this strategy is not considered the most appropriate, then the chaotic allocation strategy is followed, together with the other constraints described below. Moreover, the proximity of the reserve locations to the corresponding picking location is considered relevant in order to optimize the replenishment operation. This is achieved by creating a new parameter in the system that gives priority to the reserve locations belonging to the same aisle where the picking of the SKU in question is carried out. Finally, the size and weight parameters are considered in order to optimize warehouse space, as well as the division of the warehouse by customers and also by customer families, with the aim of making inbound and outbound operations more efficient.

It is considered that these changes in the model, when implemented in the system, constitute a possible improvement in the efficiency of operations since a reduction in the replenishment and picking times is expected. In addition, it is also expected to be a great improvement in the organization of the warehouse space, which in turn contributes to the improvement of operations.

Resumo (Portugês)

Este projeto foi desenvolvido na empresa Rangel Distribuição e Logística com o objetivo de reformular e melhorar a estratégia de alocação de produtos nos armazéns. Isto envolve a criação de um modelo ADE, (Alocação Dinâmica de Espaços) que visa otimizar os processos de receção e armazenagem com o apoio de um Sistema de Gestão de Armazéns (WMS). A criação deste modelo tem como intuito a sugestão automática, por parte do sistema, do local de arrumação das paletes rececionadas. Este projeto engloba as operações inbound e outbound tendo sempre como objetivo a otimização das mesmas, isto é, trabalhando no sentindo da redução dos seus tempos de ciclo e, consequentemente, os respetivos custos para a empresa.

Assim, ao longo deste trabalho, foram estudadas várias estratégias de alocação abordadas na literatura, bem como os métodos utilizados em três empresas visitadas, Bosch, Aapico e Parfois. Foi possível verificar que as três empresas estudadas utilizam a estratégia de alocação caótica adaptada à sua realidade. Além disso, estas possuem layouts bastante seccionados por cliente e família de cliente, o que se revela uma mais valia na redução dos tempos de arrumação e picking. Por fim, foi verificado que o sistema informático da Parfois possui uma funcionalidade de procura de locais livres consoante a proximidade do local do picking da SKU em questão.

Com base em tudo o que foi estudado foi possível criar um modelo em forma de fluxograma que engloba as várias estratégias e parâmetros que se revelaram relevantes tendo em conta a realidade da rangel. Assim, após um estudo detalhado e várias tomadas de decisão em equipa, optou por se idealizar uma estratégia baseada em classes, podendo para cada armazém e para cada caso ser adaptada. Assim, no caso de num dado armazém se considerar que esta estratégia não é a mais adequada, segue-se, então, a estratégia de alocação caótica conjuntamente com as restantes condicionantes descritas em seguida. Considera-se, também, relevante a proximidade dos locais de reserva ao correspondente local do picking, de forma a otimizar a operação de reaprovisionamento. Tal é conseguido através da criação de um novo parâmetro no sistema que dá prioridade aos locais de reserva pertencentes ao mesmo corredor onde é realizado o picking da SKU em questão. Por fim, são considerados os parâmetros de tamanho e de peso de forma a otimizar os espaços no armazém, bem como a divisão do armazém por clientes e famílias de clientes, com o intuito de tornar as operações inbound e outbound mais eficientes.

Considera-se que estas alterações no modelo quando implementadas no sistema constituem uma possível melhoria na eficiência das operações, uma vez que se espera uma diminuição dos tempos de reaprovisionamento e picking. Para além disso, espera-se, também, uma grande melhoria na organização do espaços do armazém, o que por sua vez contribui para o aumento da eficiência das operações.

Acknowledgments

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Contents

Acronyms

- ADE - *Alocação Dinâmica de Espaços*, (Dynamic Storage Allocation)
- ICOL - *Interface de Controlo de Operação Logística* (Logistics Operation Control Interface)
- WMS – Warehouse Management System
- SKU - Stock Keeping Units

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1 Introduction

This project focuses on the study of strategies for storage allocation in a warehouse in order to apply them to a Logistics Service Provided (LSP), Rangel Logistics Solutions. In this chapter the company is presented, beginning with a brief description of its context, how it is organized, the business areas in which it operates, and, in more detail, where this project is inserted. Next, the project is presented, as well as its motivation within the context of the company. In addition, the objectives of the project are presented and explained. Finally, it is described how the dissertation is structured as well as what is covered in each chapter.

1.1 Rangel Logistics Solutions presentation

Rangel is a logistics company that offers a wide range of services and, with the support of global partners, can move goods between more than 220 countries. Rangel stands out for its one-stop-store service, and besides Portugal, it also has a direct presence in other countries such as Brazil, Angola, Mozambique, Mexico, and Cape Verde, and is now expanding to Zambia.

Founded in 1980 as a customs-focused company, Eduardo Rangel quickly evolved into Eduardo Rangel Despachante Oficial in 1983 and began in 1988 by providing international transportation by land, sea, and air. Over the years, Rangel has evolved as a company, creating new services adapted to the needs of the market. FairExpo, one of the company's most essential services, was born when it became an official Expo operator in 1998. Parallel to its global expansion, the company extended out to a diverse group of markets such as Pharmaceutical and Health, Fashion & Lifestyle, and Wine, each with its activities and specific needs.

Rangel acts in multiple markets with its various services, such as Customs Services, Contract Logistics, eCommerce, FairExpo, Transportation, Project Cargo, Special Logistics, and Customer Portal, as it is seen in Figure 1.

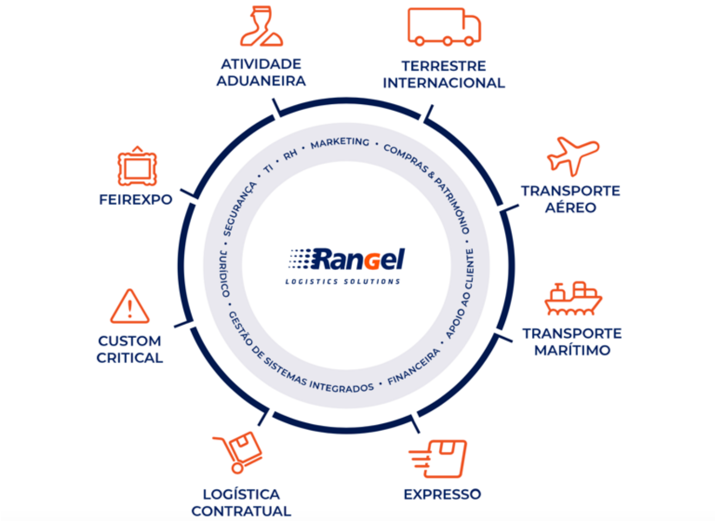

Figure 1 - The various services provided by Rangel (Apresentação Rangel, 2020).

Rangel's mission is to offer unique and personalized services to its customers, always striving to innovate and contribute to their growth. To achieve this, the company relies on its strong relationships, ability to learn, novelty, and passion—these are some of the company's values.

Rangel is a logistics company that offers the market a One Stop Shop solution for transport and logistics. The project is addressed to the warehouse area, more specifically to the inbound process.

In 2020, Rangel had more than 300 thousand logistics areas, 33 thousand clients, and 203 million euros of revenue, this translates into 5.2 million of shipping of more than one thousand million tons transported, as it is seen in the Figure 2 (Rangel Logistics Solutions, 2020).

Figure 2 - Number that represent Rangel in the year of 2020 (Rangel Logistics Solutions, 2020).

1.2 Motivation and aim of the project

Nowadays factors such as globalization, quick market changes, competition, short product life cycles, and demands for high productivity make the impact of logistics on production far greater than it was in the past. This scenario leads to considerable interest in the design, planning, and control of warehousing systems as major research topics. This evolves into a need to fight the competition, and work towards improvement, focused on constant optimization, innovation, and cost reduction of operations is fundamental (Dotoli et al., 2015).

The theme addressed in this work was proposed in order to improve the strategy of locating products in the warehouse. It involves the optimization of the processes of receiving and storing with the support of a Warehouse Management System (WMS). In this way, the storage allocation strategies are a very relevant theme to Rangel, since their application and improvement can represent an added value to the company. The place where each product is allocated has great importance because it has a big impact on the time it takes for a pallet truck to arrive there and consequently has a big impact on the total order expedition time. Thus, a reformulation of the storage strategies combined with a better redesign of the warehouse layout, can contribute to the optimization of spaces and thus to the total optimization of the process.

The application of these strategies to the WMS, ailed to a redefinition of the parameters used, translates into the functionality called ADE, Alocação Dinâmica de Espaços, (Dynamic Storage Allocation). Although Rangel has this functionality, it is not in operation. However, given its importance, the need for this project arises. In this way, the project has the goal to review the strategies taken into consideration and redefine the most relevant parameters that must be taken into account in the company's software. In this way, three goals were established at the beginning of this project. The first one involves studying and recognizing the strategies and rules to obtain a bigger operational efficiency in the inbound and outbound processes. The second one defines the most relevant parameters and production of a flowchart with requirements/conditions vs. strategies. Finally, the third goal, involves the creation of a support document for the configuration of the functionality in the Rangel’s WMS system, as a user manual.

1.3 Dissertation Structure

This work essentially consists of four parts. In the first phase, the literature review is presented, where it is intended to obtain a general contextualization of the warehouse world, how the ADE works, and how it can improve optimization in its operations. In this way this paper begins by addressing warehouses and logistics as a whole, proceeding to describe its main operations. Finally, it is presented the most important storage allocation strategies and how they can improve the warehouse operation system.

The following chapter begins to present the current situation describing the problem and its most important factors. The chapter ends by presenting the parameters in Rangel WMS interfaces that need to be taken into account when characterizing the SKUs and the storage locations in the system.

In the next chapter, the case studies based on other companies are presented, in order to collect all the useful information for the development of the project. Following, the most adequate strategies, as well as the most relevant parameters, are chosen in order to create the flowchart that gathers all the possible paths to follow when goods are allocated in the warehouse. Lastly, the user's manual is presented and how this method can be adapted to Rangel's system is explained.

Finally, in the last section, it is presented a conclusion of the preceding work as well as suggestions for future works.

2 Literature Review

The ADE is a topic that refers, as the name implies, to the allocation of products that arrive at the warehouse to a corresponding space in a dynamic way. A warehouse system that has ADE is a system that automatically indicates where each product will be stored. This system must then be programmed to indicate the location that optimizes warehouse operations, which involves, very briefly, minimizing the movements performed in inbound and outbound operations. To do this, the system must be given the necessary parameters to define both the products and the locations in the warehouse, as well as the respective restrictions, so that it is possible to find, for each case of each product, the best available location. Thus, it is necessary to know the reality of a warehouse, its main functions, operations, and needs, in order to understand its dynamics. Furthermore, it is essential to learn all the methods and allocation strategies normally used in order to be possible, with all this information, to define the necessary parameters to give to the system in the implementation of ADE. In this chapter, the topics mentioned above are presented to contextualize the subject of ADE.

2.1 Warehouses and Logistics

Warehouses are known as material handling stations that focus on receiving, storing, picking, sorting, and shipping goods. The operational efficiency of a warehouse is closely related to its success. The ability to create flow is crucial for reducing unpredictability throughout the production chain and assuring excellent service quality with minimal inventory. The warehouse must be prepared integrally for this flow to be established, which requires action not only at the physical level (warehouse design) but also at the operational and team management levels (Dotoli et al., 2015) (Tompkins et al., 2010).

To obtain this success warehouses are required to do more and better work and improve their operations. E-commerce, collaborative supply chains, globalization, quick response, and just-in-time are pushing warehouses to:

- Carry out more compact transactions.
- Store and handle more products
- More custom products and services
- More services with value-added
- More returns
- More orders from abroad were received and shipped

On the other hand, today's warehouses have:

- A shorter execution time for orders
- There is less room for error
- Fewer workers who are skilled, young, and speak English
- Limited ability of warehouse management systems (WMS)

(Frazelle et al., 2002)

One of the most successful ways for raising productivity and cutting expenses is to reduce or eliminate all unnecessary and inefficient tasks. In terms of material handling, equipment, and personnel use, inventory reduction, and quality enhancement, a warehouse design must accommodate this purpose (Tompkins et al., 2010).

Given the diversity of functions they can perform, warehouses can also be classified according to their different tasks, they can be: Raw material and component warehouses, Work-in-process warehouses, Finished goods warehouses, Distribution warehouses, and distribution centers, Fulfillment warehouses and fulfillment centers, and Local warehouses (Frazelle et al., 2002).

2.2 Warehouse Flow

The beginning of the storage process involves the action of one or more suppliers that provide the materials to be stored. It will be necessary, in sequence, to handle them, which includes receiving, confirming receipt, checking the load, storing, and then picking, shipping, and distributing.

It is important to refer to logistics or the logistics management of a warehouse as the management of physical and information flows, and this management indirectly includes the need to provide customer service. In fact, the management of physical and information flows provides value to the products, services, or solutions offered to customers, and, in this way, this management can be considered as generating value. More broadly, managing physical and information flows involves planning, implementing, and controlling those flows (Carvalho et al., 2017).

The material flow pattern within the warehouse, the specification of functional departments, and the flow relationships between departments are all determined by the overall structure or conceptual design. The size and dimensions of the warehouse, as well as the space allocation among various warehouse divisions, are determined by the sizing and dimensioning decisions. The layout of a warehouse department includes details such as aisle configuration in the retrieval area, pallet block-stacking pattern in the reserve storage area, and the configuration of an Automated Storage/Retrieval System (AS/RS).

Many commercial warehouse management systems (WMS) are available on the market to aid warehouse managers in handling products, orders, space, equipment, and human resources in a warehouse and offer storage location assignment rules/algorithms.

Within zones, items are assigned to locations, and location assignment has a big impact on storage capacity, stock control, and picking. Random, class-based, and dedicated storage are some of the storage systems that can be used which will be discussed later in the paper. The decision on which approach to utilize is both a design and an operational problem (Gu et al., 2007).

Flow plays an essential role in the performance of various warehouse operations so that a paradigm shift is necessary for relation to traditional warehouse organization. Nowadays these are based on a push planning methodology, focused on guaranteeing the existence of stock to meet customer needs. For this to be possible, the existence of high stock levels becomes critical, which on one hand may not correspond to customer orders, and on the other hand, makes the warehouse incapable of being flexible to changes in demand. Thus, management is focused on space and not on flow, resulting in inefficient processes and careless location-allocation.

A flow-based warehouse, on the other hand, is focused on a pull-planning methodology, seeking to guarantee a flow of materials that is conducive to fulfilling its obligations without creating waste in its processes. The focus is on a synchronized flow of materials, leading to shorter delivery times, lower inventory, standardized work processes, and fixed and efficient material allocations. As a result, greater flexibility, a better service level, and lower costs are guaranteed (Simchi-Levi, 2008) (Ballou, Ronald H.,2003).

2.3 Operations

The main operations of a warehouse can be segmented into two major groups: inbound and outbound operations. The inbound represents the incoming flow of the material in the warehouse, this material is received, put away, and stored in a determined space. Within the outbound, there is the outgoing flow of the material, and this involves operations like picking, sorting, and expedition, as it is shown in the Figure 3.

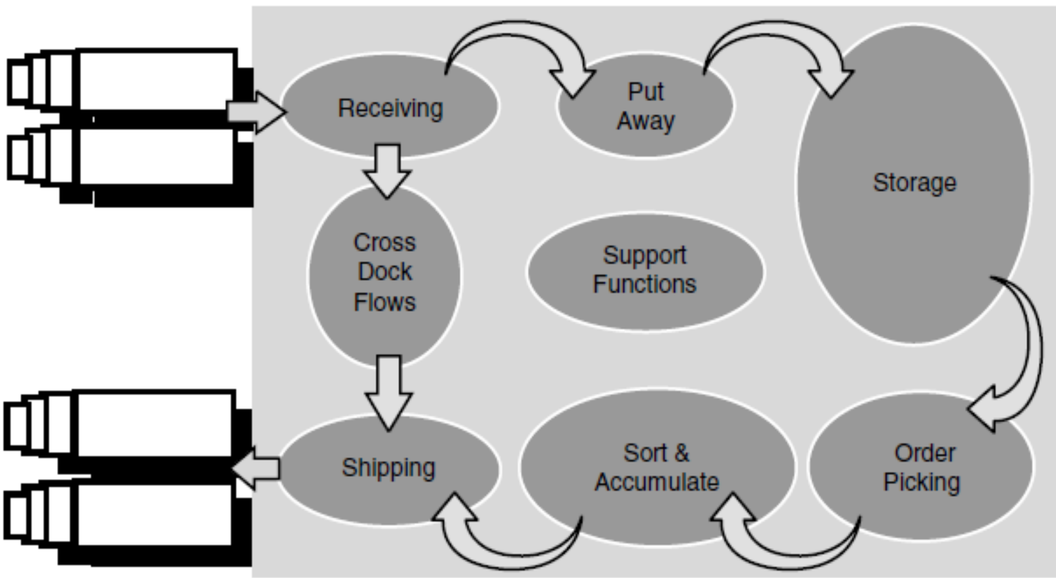

Figure 3 - Warehouse operations by (Frazelle et al., 2002).

The physical area required to accomplish various warehouse operations varies, which substantially impacts the operations' performance. Not just for effective handling, but also for packaging and sorting, receiving, and shipping spaces require ample space. Picking and put-away procedures necessitate aisles with sufficient handling and access to SKUs, which is mostly dictated by the equipment required to conduct these jobs. The process requiring the most physical space is storage, which is closely tied to the storage policy/method used (Frazelle et al., 2002) Carvalho, J. C., Dias, E. B.,2004).

2.3.1 Inbound

2.3.1.1 Receiving

The receiving process is the initial step in the process of receiving any item that arrives at the warehouse. This operation involves three key stages. Firstly, the goods that are received at the warehouse must be entered into the system. In the second phase, a qualitative and quantitative check is carried out to confirm that the type, quantity, and quality of the goods match the standards demanded from the suppliers. In addition, if necessary, the goods' expiration date is examined. Finally, the product's arrival is registered, payment orders are given, and the products are ready to be put away, either in the storage area or, in some situations, elsewhere in the organization (Coimbra, 2009) (Frazelle et al., 2002).

It should be noted that a notification in advance of the order's arrival can allow the warehouse to plan its receipt and unloading, in order to, efficiently, coordinate the rest of the warehouse's activities. Once the product arrives it is unloaded and its arrival is recorded so that ownership is assumed, and so that the product is identified as available to fulfill customer orders. The products usually arrive in larger units, such as pallets. However, mixed pallets may need to be divided into separate boxes; and loose boxes may need to be palletized for storage (Bartholdi & Hackman, 2008).

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2.3.1.2 Put Away

This procedure entails inspecting the product's location, movement, and placement in a storage position. Receiving and shipping decisions are dependent on prior knowledge of each product's inbound and outgoing flows, for which the following possibilities might be considered:

- No knowledge.
- Partial knowledge, such as the average level of material flow from an ongoing to an outgoing carrier.
- Perfect knowledge of the contents of each incoming and outgoing shipment.

In the first case, there is no rationale for assigning vehicles to wharves, and there is no rationale for assigning products to storage facilities. It's unclear whether one storage assignment rule is preferable to another one in this scenario. Under these conditions, public warehouses are commonly used by businesses looking to reduce their storage expenditures. In dedicated distribution warehouses, the second option is more typical. Finally, the last scenario is becoming more and more common through the application of new information technologies such as RFID, GPS, and advanced shipment alerts enabling it to become more widespread (Gu et al., 2007).

Depending on the storage method adopted, it may be necessary to define a new position for the product in the storing process.

It is essential that at this stage a scan/record is made to preserve the information where the item was placed so that it is possible at any time to know all the positions where a particular product is placed.

This process is quite demanding because often the storage position of the product is far from the place where the reception is performed. This activity typically accounts for 15% of the costs of warehouse operations. However, the fact that the number of picking lines per storage line is often high leads to the privilege of the proximity of the location to the shipping area, rather than the receiving area (Bartholdi & Hackman, 2008) (Frazelle et al., 2002).

2.3.1.3 Cross-docking

In this operation the material is moved straight from the receiving dock to the shipping dock, allowing orders with the same final destination to be aggregated here without the need to store the material and pick it up again. As a result, two independent focuses emerge order consolidation and storage cost reduction. The first theme defines this activity as obtaining products from a supplier or manufacturer for multiple end customers, consolidating them with products from other providers, and delivering them to common final delivery destinations. Reduced material stays time in the warehouse is aided by quick material transfer.

Storage and picking are the most expensive duties in a traditional distribution center, out of the four basic warehouse functions (receiving, storage, picking, and shipping). The first is due to the costs of maintaining inventory, and the second is owing to the labor-intensive nature of the process. Cross-docking reduces the need for storage and the operations of putting away replenishing, and picking, allowing the organization to save money on two of the most valuable tasks: warehousing and the operations of putting away, replacing, and picking. As a result, the supply chain's delivery time can be reduced (Tompkins et al., 2010) (van Belle et al., 2012).

2.3.1.4 Storage

Storage is known as one of the most important elements of supply chains. It involves the organization of the goods to be stored in the warehouse to optimize the use of space while making the material handling movements efficient. Three fundamental decisions shape the storage function:

- how much inventory should be kept in the warehouse for an SKU.
- how frequently and at what time should the inventory for an SKU be replenished.
- where should the SKU be stored in the warehouse and distributed and moved among the different storage areas.

The first and the second topics are related to lot sizing and staggering problems. The third topic is the one that involves the storage assignment decisions of each SKU to its assigned store.

When the goods arrive at the warehouse, it is expected that they will be assigned to the appropriate places in the storage area. This place must be chosen very carefully since it will influence not only the time required for the picking operation but also the cost. Thus, the best allocation possible should be chosen for each product in order to obtain an optimal arrangement. These decisions are made with a focus on two key criteria: storage efficiency, which is directly related to the holding capacity, and access efficiency, which relates to the resources needed by the insertion (store) and extraction (picking) procedures.

Figure 4 from the authors (Gu et al., 2007) shows a different scheme for warehouse operations than the one shown in the previous chapter. However, it has the same essence. In this framework, it can be seen the big three themes that involve storage in a warehouse: SKU Department Allocation, Zoning, addressed in this chapter, and Storage Location Assignment, which can be found in more detail in the next chapter.

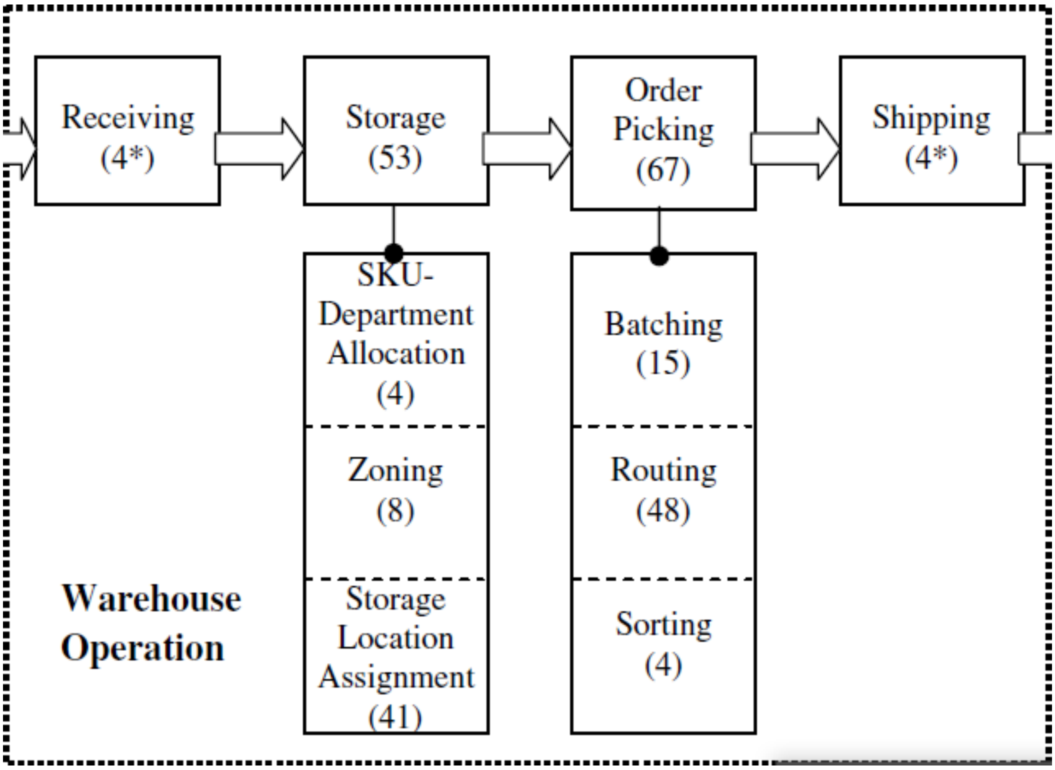

Figure 4 - Warehouse operations by (Gu et al., 2007).

One SKU can be allocated to more than one department in the warehouse. It is a design decision to specify departments in the warehouse. After the departments have been defined, it's time to figure out which SKUs should be stored in which department, in what amount, and the inter-departmental moves for that SKU. But this decision is not always so straightforward. For example, considering that a certain client is assigned to a certain part of the storage department, all the SKU of this client will be stored in this area. But in some cases, departments can be different in terms of their type of storage and kind of material-handling ability. In this way, it is necessary to make a well-considered decision in order to balance the costs and the capacities of storage and material handling.

It is a common practice in warehousing to create a separate area to pick high-demand, fast-moving products. This reduces picking costs. The zoning problem is to specify different storage zones in a department and assign SKUs to the specified zones. Thus, zoning decisions fall between warehouse design decisions. One of the main reasons for dividing a storage department into zones is to organize and simplify picking activities. The key advantage of zone separation is the limited space the operator must travel to fulfill an order (Gu et al., 2007).

2.3.1.5 Storage Location Assignment

The storage location assignment (SLAP) is the problem that involves the decision of assigning the SKUs that arrive at the warehouse to the intended storage location. This allocation should be done in the most optimal way possible, concerning each warehouse and the corresponding incoming products, in order to reduce the material handling costs and improve space utilization. In this way, different warehouses, and different warehouse departments, with different types of products might need different SLAP methods.

The storage location assignment problem is formally defined as follows:

Given:

(1) Information on the storage area, including its physical configuration and storage layout.

(2) Information on the storage locations, including their availability, physical dimensions, and location.

(3) Information on the set of items to be stored, including their physical dimensions, demand, quantity, arrival, and departure times.

With the following criteria and constraints:

(1) Storage capacity and efficiency.

(2) Picker capacity and efficiency based on the picker cycle time.

(3) Response time.

(4) Compatibility between products and storage locations and the compatibility between products.

(5) Item retrieval policy such as FIFO (first-in, first-out), LIFO (last-in, first-out), BFIFO (batch first-in, first-out). When using the BFIFO policy, items that arrived in the same replenishment batch are considered to be equivalent.

These are the guidelines to be taken into account when faced with the problem of allocation assignment. In this way, it is important to know the type of layout present and the characteristics of the storage space, which varies from warehouse to warehouse. Likewise, it is essential to take into account the type of materials that will be stored and their characteristics. When it comes to constraints, it is important to emphasize the compatibility between products and storage locations (de Koster et al., 2007).

2.3.1.5.1 Storage Allocation Strategies

Storage strategies refer to the set of rules that determine the positioning of a given product in the warehouse. The selection of the most appropriate strategy typically depends on the balance between picking effort and warehouse utilization rate. Product and supplier typology, demand variability, order types, and customer requirements are other decisive factors that have to be taken into account in this process. Typically, storage methods are segmented into 3 types of allocation which each names can vary according to the author: random/chaotic or closest open location, fixed and full turnover storage or class-based.

Random / Chaotic - Closest open location

In this method, the storage position for a particular item is chosen randomly from among the empty locations that can accommodate it. This process results in a higher warehouse space utilization rate. It is recommended to be chosen for a computer-controlled environment given the demands on information integrity. The position of an article is only defined when it is put away and it is necessary to store this information quickly and reliably. This method stands out for its greater flexibility in the use of free space, allowing the immediate occupation of more spaces (there are no fixed positions). With this organization there are no longer specific areas according to the type of product, making the adaptation process of the operators more efficient, effective, and simple: they only need to follow the guidelines given by the system and not memorize areas of the warehouse. (Petersen, 1997) (de Koster et al., 2007)

Fixed - Full-turnover storage

In this allocation strategy, each product has a fixed location defined. The need to reserve a position for a product causes the storage space to be blocked, even if there is no stock for that SKU. It should also be noted that the location must have enough space to accommodate the maximum inventory volume foreseen. As opposed to the chaotic method, the utilization rate of the locations will be lower. The fact that the item always remains in the same storage position allows picking operators to become familiar with the location, which can prove to be an advantage. Because demand can vary significantly, this method can be inefficient because of the need to make layout changes. For its implementation to be possible, good information management to support the system is critical.

Class-based storage

This method combines some of the methods described above. The goal is to create classes to which the items are allocated in a dedicated/fixed manner and then distributed within the class randomly.

The process of clustering into classes can be based on the turnover of the products with search volume. Traditionally, one of the main techniques is to divide the products according to the Pareto method. However, the number of classes does not have to be limited to the three most usual (A, B, C) used in this tool.

After defining the number of classes and the selection of products to integrate each class, it is important to think about the method of positioning these classes in the warehouse. The best strategy should be selected based on the picking routing methods, the warehouse size, and the number of SKUs per picking route. This strategy significantly reduces the times and distances traveled by the picking operator, however, there may be unbalanced use of the warehouse and congestion in the aisles with more activity(Larson et al., 1997) (de Koster et al., 2007).

2.3.2 Outbound

2.3.2.1 Picking

Picking is an essential operation in the value chain of any organization. This operation has the objective of removing products from the storage locations according to customer orders. Due to its importance to the service level, this is one of the processes that most contributes to the operating costs in the warehouse. One way to reduce these costs is to automatize the picking process, as labor costs are considerably reduced. However, this transition is not always simple, since products, as well as pallets, vary greatly in size, which makes the handling quite variable. Furthermore, the demand instability, seasonality of products, and also the large investment required to continue to contribute to the adoption of manual systems by a large number of companies. In the manual picking process, the operation becomes very dependent on the operator which makes the process performance very variable. In this way, the psychological and mental conditions of the operator play a very important role in the process' efficiency and effectiveness.

The definition of the picking method should be done in parallel with the selection of the warehouse layout and, consequently, the storage strategy, given the connection between these themes. Thus, one of the first issues to address when studying these topics concerns the possibility of separating the stock of a given item into two areas: stock for picking and stock for reserve. The main purpose of this division is to optimize operations by reducing movements. The smaller the picking area, the shorter the average distance operators will travel. It may be advantageous for certain items to remain in the reserve area only if the volume of demand is very high or if the frequency of orders is low (maybe it doesn't justify a separate zone in the picking area). It should also be noted that in most cases this process implies significant coordination in the warehouse in order to interleave replenishment cycles with picking cycles (Bartholdi & Hackman, 2008; de Koster et al., 2007) (Tompkins et al., 2010).

2.3.2.2 Sorting

Following the picking, the sorting process is performed. This operation consists in sorting the products through the orders, that is, assigning each pallet that was picked into an order. It is important that this operation is well carried out in order for there not to be any mix-up of different orders, since it is common, due to the intensity of the orders, for there to be multiple orders prepared simultaneously.

On the other hand, in some picking methodologies, the sorting can already be incorporated, in these cases, this step is no longer necessary as an alone process (Bartholdi & Hackman, 2008) (Frazelle et al., 2002).

2.3.2.3 Shipping

The shipping process in a warehouse is the last step of the outbound flow of material. Following the picking from the storage and the preparation of the orders, these are shipped to the customers using shipping docks. This operation involves the assignment of orders to trucks, the assignment of trucks to docks, and the scheduling of loading processes.

Before the orders are packed, a checking procedure is performed to make sure the order complies with the specifications in terms of quality and quantity. Then, orders need to be packed to ensure that they do not get damaged during the transportation and delivery. Products can be packed in boxes, pallets, and padded envelopes, among others. Focusing these two tasks in one location, instead of having a dedicated area for this checking process, is a good tactic for maximizing the available space in the warehouse.

After this, labels are distributed as well as all the necessary documents like waybills, delivery notes, and invoices. The orders are arranged by route of destination for them to be loaded onto the appropriate shipments (Gu et al., 2007)(van Belle et al., 2012) (Frazelle et al., 2002).

3 Problem Description

This chapter begins with an explanation of the problem of ADE itself, followed by the project proposed. Next, Rangel's WMS – ICOL, *Interface de Controlo de Operação Logística* (Logistics Operation Control Interface) is presented as well as how the parameters of the SKUs and of the storage places can be defined and changed.

3.1 The problem proposed

As explained above, the ADE is a tool used in warehouse systems to determine the optimal storage location of a pallet when it enters the warehouse. It is a very valuable feature for any storage facility, as it tends to optimize warehouse operations by decreasing the number of movements. A warehouse that does not have an ADE possibly tends to put away products in the nearest empty spot, without taking into account any other criteria other than the closest free available place in the warehouse, which is not always ideal. It is also important to also take other types of criteria into account, such as product type, product family, product turnover, and product size, among others. These are all criteria that must be taken into account as well as be considered as parameters in the system.

Imagining this scenario in a warehouse that doesn't use ADE: two pallets of two different SKUs, within the same family, same dimensions and weight, enter the warehouse, one following the other. What distinguishes them is the fact that the first has a lower turnover than the second. When the first pallet enters, it will be allocated to the nearest possible location, which causes the second pallet, which has a higher turnover, to be further away. In this case, the movements of the operations are not being optimized since the SKU that has a higher turnover, which means it will probably exit sooner, is located further away from the exit. In this way, the ADE proves to be very important in the sense that if the system has some other criteria that value product turnover in the warehouse, the situation described above would be different.

In Rangel's computer system, there is the ADE option, but this is not in operation. Although the system has been programmed, it also depends on the parameters that are entered for both the products and the storage locations, and also whether these are up to date. What happens is that the parameters of the products that enter the warehouse are outdated, and in this way, the system has stopped working at its full potential. However, it is still possible to "ask" for the system's suggestion on the storage location, but this is not always followed. This way, it is up to the operator who is going to store the pallet to decide where to place it. Normally, he may choose, within that SKU's customer zone, a free place that is closer to the entrance in order to speed up the inbound process. However, this decision can vary. With time, an operator gets used to the warehouse operations, the customers, and even the product families of each client. He also realizes that each type of product normally tends to be stored in the same area. So, if a certain SKU from a certain product family arrives at the warehouse, the operator, knowing the warehouse, tends to store it closer to other products of that same family. In addition, it can happen that a certain product that was previously in stock and was in a certain zone will also be placed in that zone. Of course, this is not always easy and ideal since the lack of specific criteria in the system will make those same places easily full or even occupied by other families of products. In this way, the opportunity to develop a product allocation model that meets the needs of Rangel warehouses arises.

3.2 Rangels' WMS – ICOL

The company has its own WMS named ICOL. This system tracks and supports all warehouse operations: reception, storage, picking, replenishment, and internal transfers to other value-added services such as labelling, validation, sorting, and expedition. ICOL works as a way to control everything that goes on in the warehouse. It is a software where all important information is cross-referenced. ICOL's goal is to ensure that goods are handled through the warehouse in the most effective and economical manner possible. Through this software, it is possible to access various information, among which the entire inventory, all its data, as well as each SKU location, the supplier orders that will arrive at the warehouse, as well as the client orders that Rangel receives.

There are different ICOLs for the different Rangel's warehouses since each one has a different database and possibly different functionalities according to the type of customer.

When an SKU arrives at the warehouse, it is first assigned to a "mass" location, which is a virtual position in the warehouse. This happens because the unloading process is a very busy operation, many products arrive at the same time, and, in order to streamline the entry of products into the warehouse, this virtual location is assigned in order to be able to move forward with the process. This allows customers, at the end of this phase, to see that the product is already in stock. Otherwise, clients would have to wait for them to be put away before they could access the information in their system.

Later on, the storage of the pallet, as mentioned before, is done by the operator. This one uses a device called an RF SCANNER that allows the worker to associate the product with the storage place by scanning the bar code on both the product and the storage place. In this way, the operator will go to the area of that client and then to the aisle where he wants to store the pallet. He will then check if there are any places available where it is possible to store that pallet and proceed to store it. Once the operator finds a storage place where he wants to allocate the pallet, he associates that pallet with that place by scanning both the code bars of that SKU and that storage place.

With the help of this new method developed in the course of this work, it is intended that in the future the system will suggest the most suitable storage location for that product. In this way, initially, by scanning the barcode of the product, the system will determine the optimal storage location to store that pallet, taking into account its specifications. This method optimizes the process not only at the moment of storing the products but also in the future picking process.

3.2.1 Products and storage location parameters

As mentioned before, the ADE was once programmed, but the data related to the parameters that were previously defined is outdated in the system. If it was fully working, it would indicate the optimal option of storage location.

Through ICOL, it is possible to access the properties of both the storage locations and the SKUs. Here, by selecting a certain product, it is possible to consult and define some of its parameters, as shown in Figures 5 and 6. And the same happens with storage locations. This is the general information that characterizes the product and the storage places, and it is useful not only to parameterize them in terms of ADE but also to define how some other operations are performed.

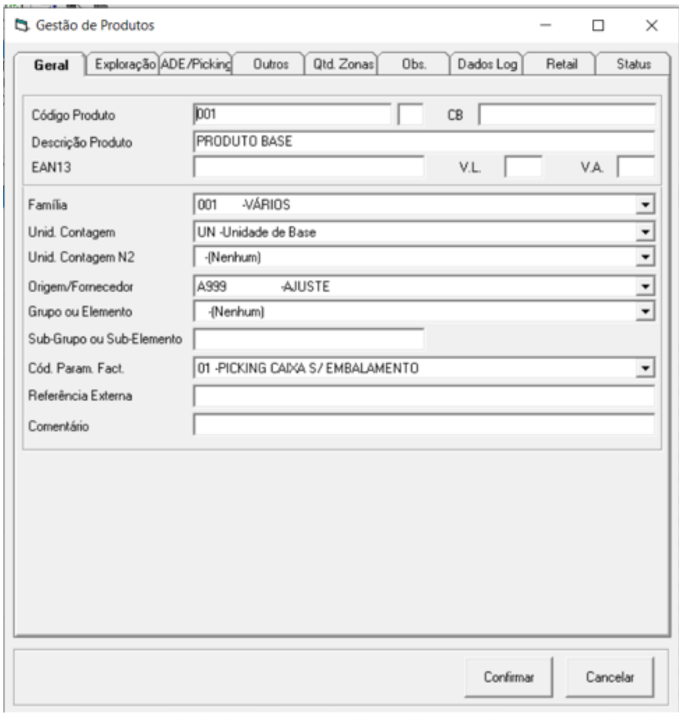

Figure 5 - General parametrization for SKUs.

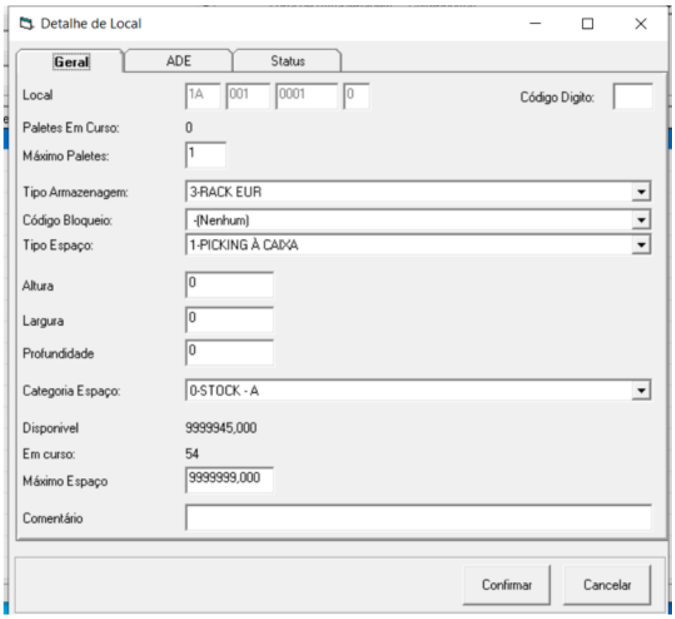

Figure 6 - General parametrization for storage places.

From this ICOL functionality, it is also possible to see and alter the parameters for each product and storage location in order to satisfy the ADE, as can be seen in Figures 7 and 8. These are more specific parameters that involve chaining sequences and orders of preference. These properties are essential for the system to know which parameters are being prioritized and, in this way, find the best allocation option possible.

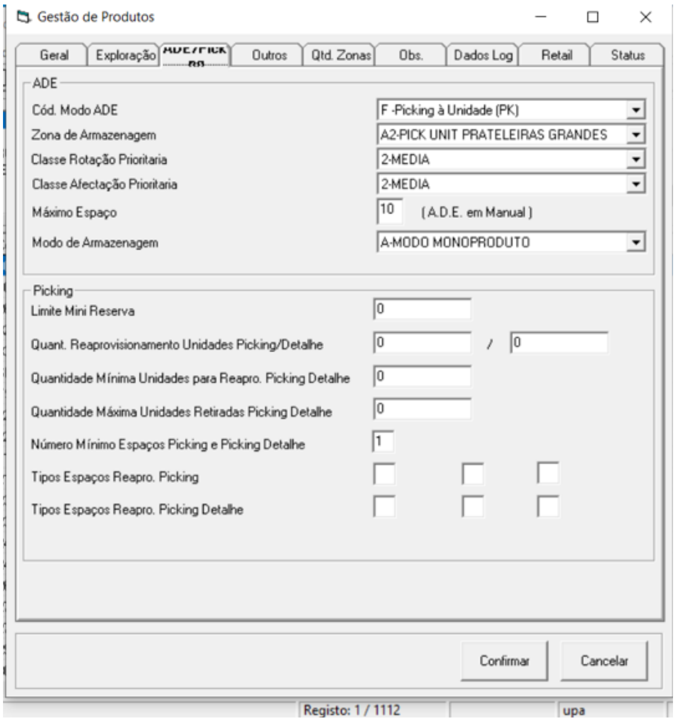

Figure 7 - ADE parameters for the SKUs.

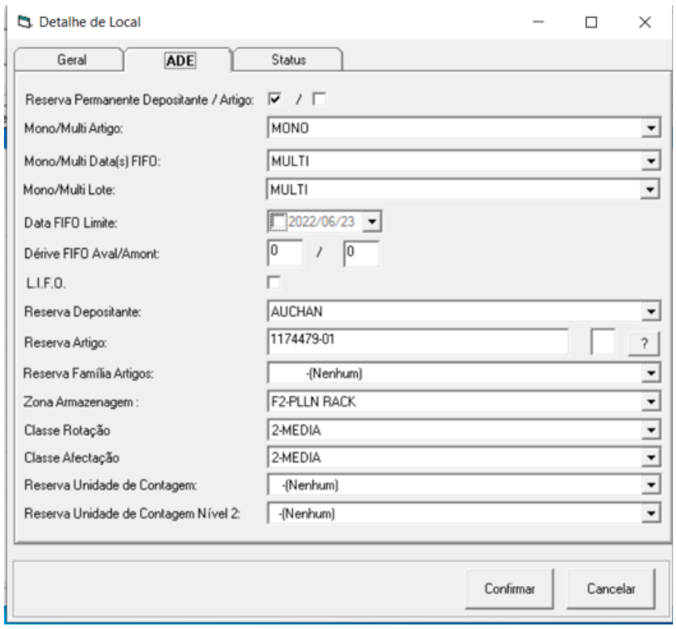

Figure 8 - ADE parameters for the storage location.

From the information about each product and each storage location, as well as their respective parameters, it is possible to cross-reference all the information in the system and this one will indicate the optimal location for a certain product. This is done by matching the same parameters from each product to each location.

Observing Figure 7, in the case of the product, first it is important to define the type of ADE that is being used. Initially, when the system was programmed, this would be the "base" system. However, this can have several levels depending on the warehouse or on the clients that are being dealt with, and also the constraints that these imply. Thus, in the case of Auchan, for example, the ADE used was the "F".

Next, the storage area is indicated. This may depend on the type of product that it is being allocated: is it a product for reserve? Is it for picking? If it is for picking, is it for picking by unit or picking by box? These possible constraints depend on the type of ADE that is being used. There may be customers whose products these types of parameters are not applied.

Many times, the storage area can take into consideration the family of the product. So the warehouse can be divided into zones of different families, and the products of a certain family can be assigned to a certain zone. This allows products from the same families to be allocated together for convenience.

For some customers, certain products may need specific conditions in the warehouse and therefore require a specific zone. In the case of the Pharma warehouse, where medications are stored, it makes sense to have a "cold" warehouse zone for certain types of medications classified as such. In this way, in this case, the product's family may be characterized by "cold" and it will be destined for the "cold" storage zone.

Next, a class turnover is assigned. Ideally, a study of the products present in the warehouse is conducted and a class 1 - low, 2 – medium, and 3 - high is assigned. The same is done concerning the warehouse layout: a study is made of the most easily accessible locations, usually those closest to the exit, and the highest class is assigned, the intermediate ones are assigned a medium class, and the most distant ones are assigned a low class. In this way, each product is matched to its storage location.

It can be seen that both the storage locations and the products are classified as class 2 - medium. This was not a coincidence. In reality, Rangel's warehouses have not been working with the class turnover system, which causes everything to be placed in class 2 - medium. Due to the volatility of the products, or their constant change, the study regarding the class turnover is not easy. In a warehouse in which the products are always changing, it is necessary to constantly update the information. Plus, there is a big problem that is added when new products come in: when there is no product history, what class is it assigned? These are all questions that don’t have only one answer. This theme will be addressed in more depth in the next chapter.

Regarding the allocation class, it works in the system the same way as the class turnover previously described. This class can take into account whatever parameters that are intended. For example, it can be regarding pallet sizes. In these cases, it is necessary to "block" certain storage locations because some pallets don't fit. It is possible to create an allocation class that involves size levels. So, just like in the class turnover, the system will match the products of class 1 to the class 1 locations, that is, the smaller sizes, for example, to the smaller locations.

It is based on these parameters already used in the system that the new allocation model developed was created. Throughout the fourth chapter, it will be described the new model that was thought out that will take into account the necessary parameters to be introduced in the system in order to characterize both the SKUs and also the storage locations Thus, in the user's manual at the end of the following chapter, it will be explained how it is possible to adapt the new model developed to the system, as well as some change suggestions that were considered relevant.

4 Methodology

After all the theoretical research, the need for a practical investigation arises. This chapter begins with a description of the three companies visited, followed by a summary of the most relevant strategies used by each warehouse. Next, the methods relevant to Rangel's model are chosen, and this decision-making is explained. After that, the parameters as well as the search sequence rules that are considered the most relevant are introduced. Following that, in order to illustrate the method behind it, the main paths of the flowchart are presented as well as the strategies adopted. Finally, the user's manual is presented, where it is explained how this model would apply to the ICOL system and how to adapt the model to the particularities of the various types of warehouse storage.

4.1 Case Studies

Throughout this work, visits were made to some companies in order to collect data about the allocation and strategies used. Three different warehouses were visited, starting with Bosch, one of Rangel’s clients, Aapico and Parfois which, despite representing different logistic realities, represent very important and useful examples for this theme. In this chapter, it is then possible to find a case study made on each one of the warehouses.

4.1.1 Bosch

Bosch, one of Portugal's largest exporters, is one of the corporations that invests the most in research, development, and innovation, believing that they are the key to the future. It is supplied in Portugal by three units: Bosch Car Multimedia (Braga), Bosch Security Systems (Ovar), and Bosch Terotechnology (Aveiro), all of which are based on the creation and manufacturing of "Technology for Life" in order to improve people's quality of life.

Its Braga facility is part of the Automotive Electronics division and focuses on multimedia solutions and automotive sensors development and production. Rangel has been managing the logistics operation of this unit since 2019, where it ensures import reception services of raw materials and finished products from Bosch's national and international suppliers, as well as storage and supply of the factory 24 hours a day, 365 days a year, depending on production orders. In this way, the warehouse belongs to Bosch, but it is Rangel that runs it and controls all the operations. This means that, in the warehouse, Bosch is the only customer and all the operators, supervisors, managers, administratives, and so on work for Rangel. Although it is Rangel who operates, specific issues are required from Bosch, like some methods or ways of handling.

The warehouse is divided into two fictitious "warehouses" with separate areas: a raw material zone and the finished products zone. These areas are physically divided in the warehouse: the left racks are reserved for the raw materials, and the right ones for the finished products. Each of these zones has its own system since the databases and, consequently, the specifications of each are different. Although this physical separation exists, it is possible to adjust it to each storage area's needs. In this way, if there are not enough places, for example, in the raw material area, it is possible to block some spots in the area of the finished products to allocate raw materials. It is important to note that the type of storage is in vertical racks divided by aisles.

Starting with the raw material warehouse, it can store six pallet sizes: L1, L2, L3, the most common dimensions stored in the racks; and L4–oversize expansion; BW–large box; and KA–small box. When a particular pallet arrives at the warehouse, it must correspond to one of these previous dimensions to fit into one of the storage areas. Usually, the suppliers already send the pallets in the correct sizes; however, some don't. In these cases, it is necessary to do a repalletization before the products are stored. This procedure can be done by rearranging the products' boxes within the pallet, when possible, or it can require a rearrangement into other pallets. In the second case, the last pallet to be constructed may not be the same size as the others. After this step, the pallets are ready to be stored.

When it comes to storing the products that arrive at the warehouse, the storing is done from the right to the left of the available storage places, as shown in Figure 9. This means that when a specific pallet enters the warehouse, it will be stored in the first place available for its size, searching from the rightest rack to the most left rack.

However, there is a particular case for a specific type of product in which the storage method may vary. If a product is for rework, there is a specific area in the warehouse intended for it closer to the entrance/exit. Considering Figure 9, it would be the bottom locations of the 10th, 9th, and 8th aisles. So, in this case, the method of storing from the right to the left of the warehouse doesn't apply. These goods enter the warehouse and quickly need to exit again, so they are stored in a much more easily accessible location. This type of product has really high turnover, and this type of method is usually used to reduce the movements significantly in the warehouse.

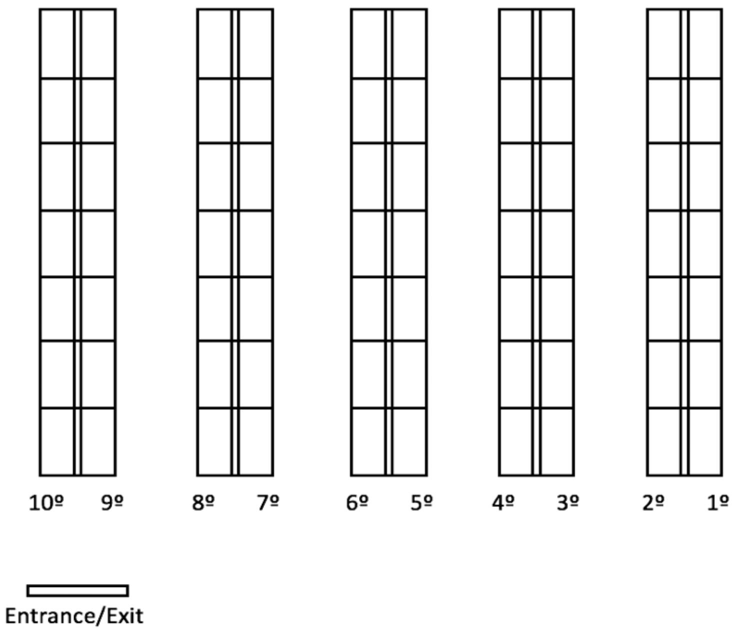

Figure 9 – Scheme of the racks' layout in Bosch seen from above.

It is also important to mention that in each aisle, the storing is done from the places nearer to the entrance/exit to the ones further away, and within each column, the products are stored from bottom to top. In this way, it is important to notice that in a particular aisle, first and preferably, each column is filled from the lowest shelf to the top shelf, starting from the first to the last column down the aisle. In Figure 10, there is a scheme that exemplifies what was described previously.

1.1.5	1.2.5	1.3.5	1.4.5	1.5.5	1.6.5	1.7.5
1.1.4	1.2.4	1.3.4	1.4.4	1.5.4	1.6.4	1.7.4
1.1.3	1.2.3	1.3.3	1.4.3	1.5.3	1.6.3	1.7.3
1.1.2	1.2.2	1.3.2	1.4.2	1.5.2	1.6.2	1.7.2
1.1.1	1.2.1	1.3.1	1.4.1	1.5.1	1.6.1	1.7.1

Figure 10 – Scheme of the first rack seen from the front.

When there are no available spaces of a specific size in the warehouse, several situations can occur with different levels of complexity. First, addressing only the sizes: L1, L2 and L3, if there are no available spaces of the size L1, it is not critical, as the dimensions of L1 are smaller than the other ones, so the pallet can be stored in one of the other spaces. However, this situation is not ideal because the warehouse space is not being optimized as the spaces are not being used to their full potential. On the other hand, if there are no places for an L3, it is more concerning, as pallets with this dimension do not fit anywhere else. In this way, it is essential to prioritize leaving the bigger places as free as possible. In order to contribute to this, when coming across this situation of no available spaces, the system may suggest one of the following alternatives:

1. Rearrange the pallets in question into another size
2. Change the limit of the fictitious warehouses
3. Store the pallet in a bigger space.
4. Release one of the spaces with the desired dimensions and rearrange the pallets in some other way

The first option is to rearrange the pallet in question, making it into a smaller dimension. In one way, this is always done once it is prioritized to optimize storage space. As mentioned before, the two warehouses have different areas for the second hypothesis, but these can be adjusted. For example, the Finished Goods warehouse will block storage places at the entrance, and the Raw Material warehouse will create positions in those places now blocked. The third option is to store the pallet in the next bigger space. The last option, and the most avoided since it requires two handlings, is to free one of the desired places.

For the finished products, on the left side of the warehouse, the strategy used is essentially the same, with some differences due to product specificities. In this case, the products arrive at the warehouse in eight different types of pallets, which vary in size. These pallets don't need repalletization once they come directly from the factory in standard sizes. As it occurs in the raw material warehouse, the pallets are stored from right to left, except for some products that need to be kept in the cage, a locked and more controlled area in the warehouse. In these particular cases, the products are stored there because they are more valuable, need better supervision, or have a greater risk of something happening to them.

4.1.2 Aapico

Aapico is a company with Thailandese origins that has been in Portugal since 2007, having now three industrial units in Maia, Águeda, and Trofa. It began with the goal to design, develop and produce critical automotive safety components such as brakes, suspension, gearbox, engine, and powertrain in nodular iron. The company specializes in producing lightweight casting solutions for companies such as Volkswagen, Mercedes, and BMW.

Concerning Maia's industrial unit, it is divided into three areas: production area, warehouse, and offices. This analysis will focus on the dynamics and organization of the finished product warehouse. Thus, after the reception of raw materials, production and manufacturing of the new parts, quality control, etc., the final products, ready to be shipped to the customers, are stored in the warehouse.

Aapico's warehouse uses the storage system of block stacking, as can be seen in Figure 11, which differs from Rangel's warehouses. Pallet blocks are stacked on top of one another and placed in lanes on the warehouse floor, with the lane depth equal to the number of pallets stored back to back away from the picking aisle. Each lane is designed for only one SKU, so each has a destined place in the warehouse.

Figure 11 - Image of Aapico's warehouse

Regarding the packaging, each SKU has a specific appropriate packaging depending on the product type. The products are essentially stored in wood, metal, plastic or card boxes or big bags. Every kind of packaging may vary in size depending on the product and also depending on the client, each client may have their specifications. In this way, the warehouse is divided into several "areas" that are destined for a type of packaging. Thus, the warehouse is grouped by types of packaging and clients. In addition, when the warehouse layout was designed, each box area was chosen based on the class turnover (A, B, C) of the SKUs. In conclusion, the products are grouped by SKUs, which are grouped by types of packaging, which are grouped by customers.

In this way, Aapico mixes a range of storage strategies and adapts them to their needs. It can be considered that there is a division by families, with each family having its type of packaging. Dividing each family by zones, the company is taking a fixed storage approach, since each zone will be assigned to a family of products and customers. However, in a way, within each zone, the strategy ends up being chaotic, since there are no specific allocation criteria, and often the closest empty space ends up being chosen.

In review, this type of storage works well in Skathi once stored products are usually the same. As the warehouse is directly connected to the industry's production line, and the pieces produced are the ones on Aapico's catalog, it is possible to design the warehouse layout based on them. In this way, dividing the storage areas according to the different SKUs makes sense, since it simplifies the picking. Once the operator likely gets used to where each product is at and when he is doing the picking, it does not take so long to look for it.

4.1.3 Parfois

Parfois is a global accessories brand created in 1994 in Portugal. With the ambition to be the number one accessories store in each market that it is inserted, it is currently spread across 71 countries with more than 1100 stores. Its product range is mostly divided into bags, jewelry, apparel, shoes, watches, hats, scarves, and glasses. Parfois focuses on making good quality/price relationships and creating smart and stylish products.

Parfois has a large logistics center in Canelas, Vila Nova de Gaia, which was visited in order to observe and analyze its operations. The warehouse, as well as its operations, are quite extensive, in that way, in this chapter, it is made a brief description of its operations, giving more emphasis to the areas that have the most interest in this theme - the problem of the storage allocation and the operations directly related to it.

The logistics center is divided into two different warehouses that are connected through a hallway: the "Inbound" warehouse and the "Outbound" warehouse. In fact, the warehouse is, all the same, however, the operations performed in each area are essentially different. In this way, the first warehouse deals essentially with operations related to inbound, reception, conference, put away and storage, while the second warehouse is in charge of sorting and shipping The products when they arrive from the supplier, are unloaded in the first warehouse. In this warehouse, the storage is done in Single-Deep Pallet Racks whose storage locations are all the same size, except on the top floor, which will be discussed later on. In this way, when the pallets arrive, the products are checked in order to verify that everything is as intended. After that, the pallets coming from the suppliers are shredded and reconstructed to match the size criteria used in the warehouse. Only one pallet model is used - Euro Pallet. Next, there is quality control by sampling and after this process, the pallets are ready to be put away.

In terms of layout, the warehouse is arranged in such a way that the entrance is on one side and the exit is more or less in the middle, as shown in the scheme in Figure 12.

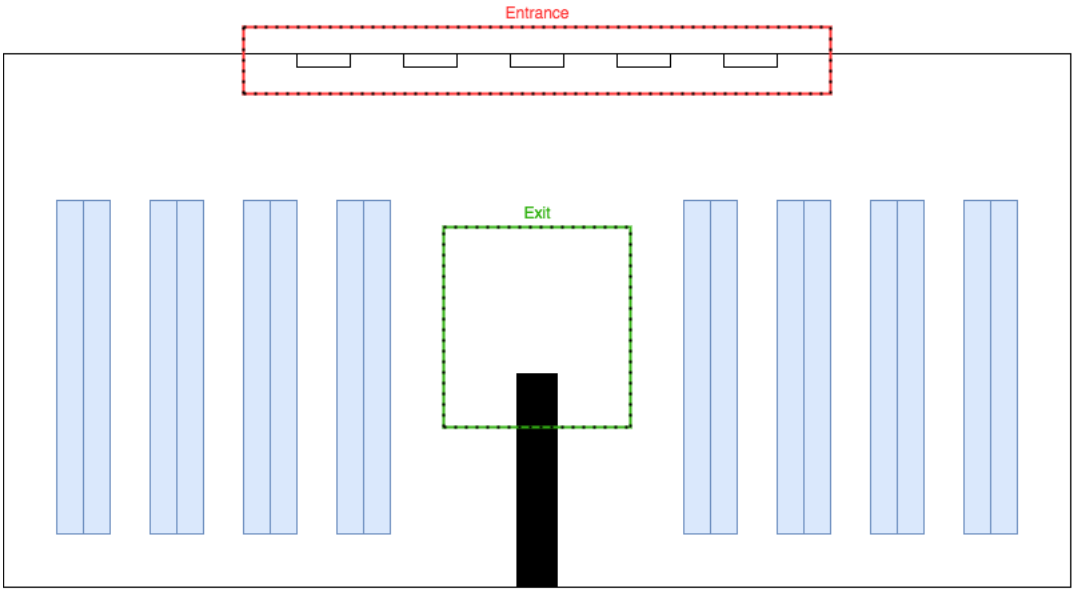

Figure 12 - Scheme of Parfois' warehouse.

The exits are performed through a system of conveyor belts that make the passage between one warehouse and the other. Furthermore, it is important to mention that the warehouse is divided by product zones on the floor level, the picking zones (picking for the other warehouse, not for shipping). Each of these zones is destined for a specific range of products, which can be understood as a product family, for example, wallets, shoes, glasses, etc. The borders of these divisions are not strict, and they can change as needed however, the system gives preference to the products of that zone's family.

Parfois does not do any class turnover analysis regarding the distribution of the products in the warehouse since the collections are always different and orders to suppliers are only made once. Each product only passes through the warehouse once. This reality makes the study of product turnover useless since each product that enters the warehouse is a new product with no previous history.

In this way, instead of using the class turnover criterion, Parfois mostly uses the density criterion. To explain, the density of a product's pallet varies according to the type of family. That is, a pallet of bags is less dense and has fewer bags than a pallet of sunglasses. The lesser dense a pallet is, it tends to empty faster and therefore ends up having a higher "turnover" and is, therefore, placed closer to the exit. In turn, denser pallets are placed further away from the exit. Thus, the layout of the picking spots is chosen according to these criteria.

In what concerns the reserve storage places, each pallet is placed according to its product picking spot. This means that, when storing a pallet, firstly, the system takes into account the location of the picking, and then it searches for the closest available spot around it, searching in a "circle" as seen in the scheme in Figure 13. Firstly the system prioritizes the yellow areas, the orange, the reds, and so on.

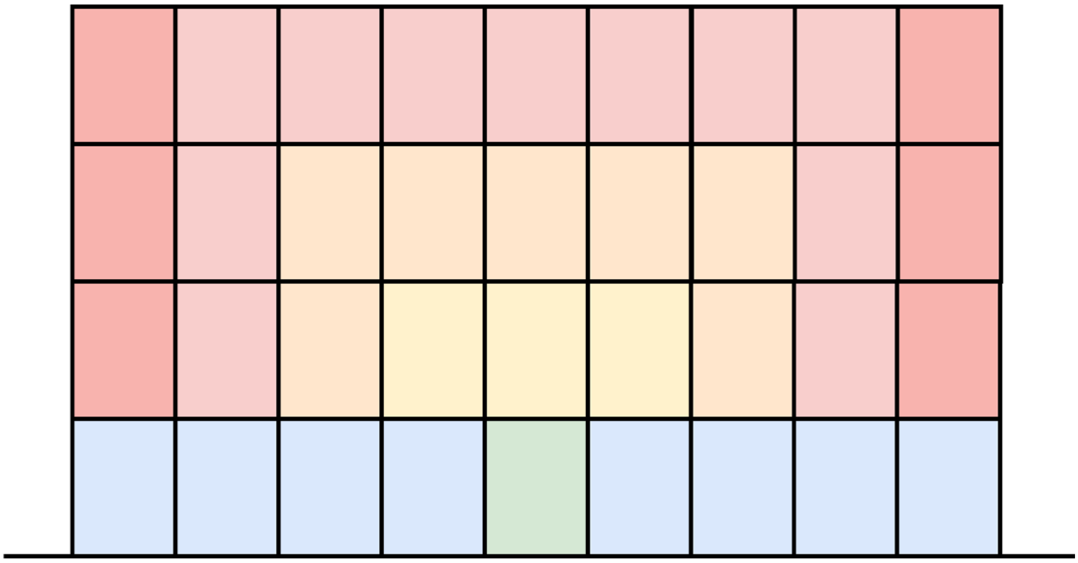

Figure 13 - Scheme of the order of allocation regarding each picking bin.

These storage places are not divided into zones and are mainly all the same size, so the only criteria considered is the proximity to the picking. There is just an exception in what concerns the storage sizes. Has the warehouse roof is inclined, some of the last storage places, on the last floor are smaller than the others. In this way, the system doesn't suggest these smaller places when searching for a certain place for a normal-sized pallet.

For these lower dimensioned places, there is a particular storage strategy. As was mentioned before, the pallets are constructed with a standardized size when the products arrive at the warehouse; however, the last pallet is always smaller. When storing these smaller pallets, the system prioritizes the smaller spots on the fourth floor and then the closeness to the picking zone. When picking a product with these smaller pallets in stock, the system also prioritizes it, and this pallet is the first one to be emptied.

4.2 Process of choosing relevant parameters and methods

After the theoretical research as well as the practical investigation based on the case studies presented, it is now possible to draw conclusions about the most relevant methods to adopt at Rangel. In order to organize the most important information from each warehouse, Table 1 was constructed.

Table 1 - Table of comparison of the three studied warehouses

	Warehouses		
	Bosch	**Aapico**	**Parfois**
Warehouse's organization	Division into two storage sections	Division into customer zones and into types of packaging zones	Division of the picking storage places into family zones
Separated zone	Separated zone for rework SKUs	-	Separated zone for consumables products
Type of storage	Single deep racks	Pallet blocks	Single deep racks
Dimensions of the storage allocations	Different dimensions	-	Same dimensions
Type of storage allocation strategy	Chaotic allocation	Chaotic allocation	Chaotic allocation
Order of filling the storage places	From the aisle most to the right to the one most to the left. Within each aisle, the allocation is done from the places closer to the exit to the ones further away and from bottom to top.	The operator chooses the storage place within that SKU area	For each picking bin the searching is done in "circle"

Based on this table, it is possible to conclude that despite being different warehouses and belonging to different realities, the three companies adopt the strategy of dividing the warehouse into different storage zones. In Bosch's case, the warehouse is divided into two large product zones, which can be understood as two different storage sections – the raw material warehouse and the finished product warehouse. In addition, another storage section can be considered—the cage zone. On the other hand, at Aapico and at Parfois, the division can be understood as a division by customer and family zones.

In addition, and despite their differences and different application methods, the three warehouses use the same type of allocation strategy: the chaotic allocation strategy. Thus, although there is a division of the warehouses by zones at both Aapico and Parfois (customer zones or family zones), within each zone the allocation ends up being random. This means that the allocation of a certain product to a certain storage place is not fixed, nor does it follow a class turnover strategy. However, this allocation is not completely chaotic and is, in a way, an adaptation of this strategy to each of the warehouse's realities. Each warehouse uses this strategy but applies it according to certain criteria and restrictions. Moreover, in Bosch and Parfois, the allocation sequence in each of the zones follows a certain logic, unlike in Aapico. In Bosch, the allocation is done from the aisle closer to the right to the one most to the left, and within each aisle, from the places closer to the exit to the ones further away, and from bottom to top. In Parfois, for each picking bin, the searching is done in "circle".

4.2.1 Layout

In order to decide which parameters and methods to follow, first it is necessary to understand what kind of layout a warehouse should have. Based on the cases observed and based on the reality of Rangel's warehouses and clients, a set of criteria were gathered in order to create the optimal storage allocation model possible. It is very important to emphasize that all decisions about the layout of a warehouse should be made by the layout design team of each warehouse based on the specific characteristics of this one. The layout of a warehouse should be designed in order to optimize the movements of the operations to the fullest. This can be done by minimizing the distances traveled by the operators in each process. The distribution of the products throughout the storage locations can be chosen by focusing on minimizing the inbound movements or the outbound movements. At Rangel's warehouses, the biggest costs are associated with the picking process, so it makes more sense to focus on optimizing this operation. In order to do this, it is important to minimize the distances that are more covered and group the SKUs in a way that makes sense considering the type of orders received. With this, each warehouse has its own specificities and needs, and it is impossible to generalize. However, there are certain important criteria on which it is possible to base these decisions and adapt them to each case. In this way, the question of dividing the warehouse into different storage zones is considered quite relevant. Logically, these divisions can vary depending on the type of warehouse in question. However, there are some divisions that are considered relevant in most types of warehouses. Thus, the model that has been thought of was designed to be applied to various types of layouts, making it only necessary to adapt the desired parameters.

Firstly, in the case of warehouses with more than one customer, the division by customer areas is inevitable, since it allows much better management of each customer's SKUs as well as greater efficiency in outbound operations. Concerning the case studies presented in the previous chapter, Aapico's warehouse applied this method since it helps to optimize the picking, and thus the entire outbound process. Also, considering that in Rangel's warehouses each order received by the warehouse will be only from a single customer, it makes sense to maintain the organization it this way. Besides this, it is also important due to the next adopted strategy presented: a division by families within each client area.

As it occurs in the Parfois warehouse, it was decided together as a team to divide each customer area into product family zones. This division allows grouping SKUs into product types and thus organizing the warehouse in a more logical and practical way. This aggrupation can be done according to what one wants to prioritize. It can be by product ranges, sizes, or types of packaging, as in Aapico, among other options. This division can be quite relevant due to the reasons mentioned earlier in chapter two, for example, in cases where there is a correlation between products within a family. That is, when several SKUs have a similar frequency in a picking order, or when there is a high frequency of them entering the warehouse together. This is verified at Rangel warehouses since similar products are always ordered from the same supplier.

Besides these divisions, it was also decided as a team to consider the strategy based on class turnover. Thus, within each family zone, the storage locations were divided into classes A, B, and C, with A being the zone destined for higher turnover, B with medium turnover, and C with the lower turnover. Although none of the warehouses studied used this allocation strategy, it was considered important to include this hypothesis in the model. This approach was adopted because, in the case of a warehouse whose stored products have a great difference in terms of frequency of entry and exit, it might make sense to have this type of distinction. Although, is important to remember that the use of this parameter represents only an option in the system; when in a warehouse where this division does not help to improve operations, this option can be switched off.

Most of Rangel's warehouses have an arrangement in which the entrance and exit are on the same side, and not on opposite sides of the warehouse. In Figure 14, a scheme of the warehouse arrangement that was considered can be observed.

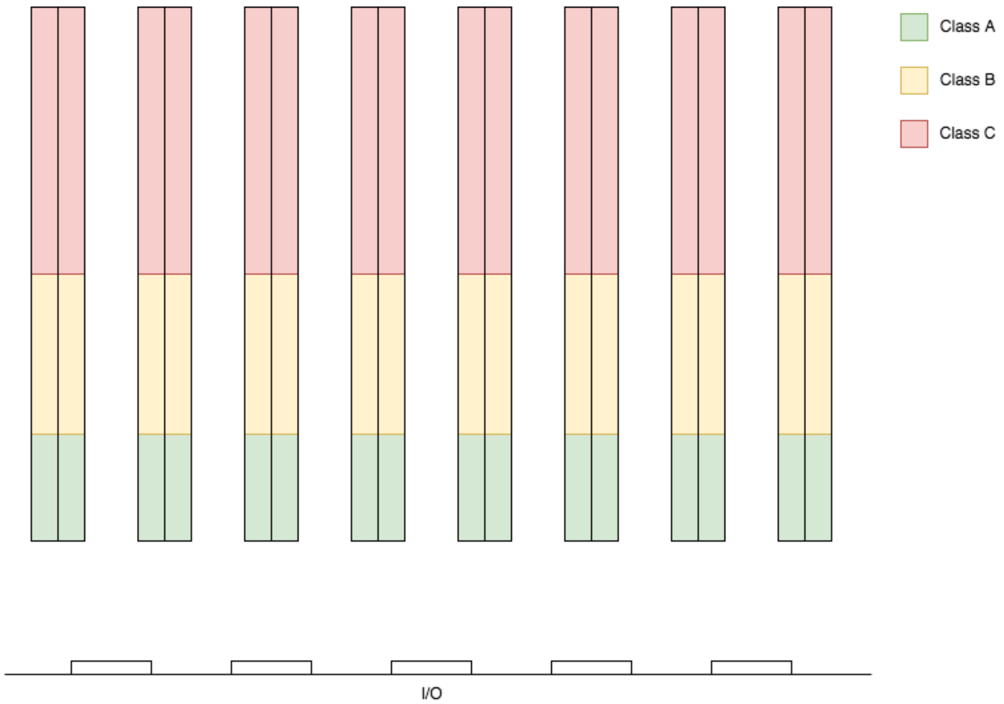

Figure 14 – A scheme of an example of a distribution of the class turnover in a hypothetical warehouse.

There are several strategies for the layout of the various class turnover areas in the warehouse, depending on the process that one wants to pay more attention to. Since, in general, Rangel warehouses tend to focus on optimizing the picking as much as possible, this is the operation taken into consideration. Thus, to optimize the movements in this outbound phase, it was decided to place the class A area closest to the exit, then the B, and finally the C.

It should be noted that these divisions by zones, customer zones, family zones, and class turnover zones, as observed in the Parfois warehouse, are more related to the picking bins, and locations on the floor. Although this same division might be considered in the reserve locations, these are more flexible due to the variability of the locations available in the warehouse. In this way, it is within the scope of the warehouse layout design to divide and organize the customer zones and their families more effectively. Thus, in the model presented, it is considered the possibility of the SKUs in each warehouse being arranged in this way: by customers, by families, and by class turnover, in an optimal way for the warehouse under consideration.

As was mentioned before, these divisions are only taken into consideration if the warehouse in question so wishes. If a division by product families or even division by class turnover is not relevant, these sub-zones can be eliminated from the model. Besides, it must be taken into account that if these zones do exist, a study performed by the Layout team is required in this sense. In the case of the division by families, as previously mentioned, these can be grouped according to the characteristics that the warehouse considers most relevant. The class turnover, on the other hand, requires a study of product turnover in the warehouse. Note that in the case of a warehouse whose inventory is very variable, the implementation of this class is not so easy.

It is also important to stress that the strategies adopted and the model developed in this chapter take into account the storage on the top shelves, in the reserve areas. This allocation will be conditioned by the respective SKU’s picking locations and also the respective zones, according to the order of criteria presented later in the chapter.

4.2.2 Storage sections in the warehouse

In addition to the division into customer zones, product family zones, and turnover class zones, a warehouse should also have distinct storage sections. These sections refer to the large area to which the product belongs within the warehouse. For example, some warehouses, such as Bosch, need a more protected zone to store higher-value products, in these cases, safety cage zones are utilized. Thus, a specific area of the warehouse is enclosed with grids and the respective entrances and exits are more controlled. In this way, it is possible to obtain greater security and control over certain products.

In addition, in certain industrial warehouses, some of the products stored may require certain specific conditions, such as temperature conditions. In the case of Rangel Pharma's warehouse, certain pills need to be stored in cold temperatures. Thus, the warehouse has a designated area for products that have this specification. It should be noted that these two areas are two examples of different storage sections that can be taken into account in a warehouse. Thus, the model was made considering also the differentiation by storage sections, which can be later defined according to the needs of each warehouse. In this way, and as it will be better explained later on in this chapter, this parameter can be adapted to the warehouse in question. Also, the location of these areas may vary according to the needs and the specificities of each warehouse layout. Therefore, it is the decision of the warehouse and the responsibility of the Layout team.

It is also important to notice that within each of these areas, there could be stored SKUs of various clients, various families, and various turnover classes. In such a manner, the division of the areas described in the previous topic is verified within these storage sections.

Furthermore, there may be certain customers that have a range of products with noticeable sales value affected by seasonality. For example, certain SKUs that have a high sales value in the summer, but not in the winter months, and vice versa. It is considered to not be so relevant to assign them a certain turnover class if it is already known that this class will change within a few months. Thus, in addition to the division by families and by class turnover, it is considered relevant, for certain customers where there is such seasonality, to also have a specific zone within the customer's area for seasonal products. In this way, these products are allocated to a better access area in the warehouse according to the time of year.

It is relevant to add that within each seasonal zone there is no division by class turnover. Thus, when a certain SKU is in its high season its class turnover is not taken into consideration. These parameters become relevant again when the season changes and the product starts being allocated outside of the seasonal zone.

Regarding their location, it was considered important for them to be in the most easily accessible positions, closest to the exit, this means, the first position in an aisle. However this can be decided by the layout team of each warehouse.

The storage zones can also serve to differentiate the allocation zones of certain pallets. If a warehouse works with several types of pallets, but not all of them can be allocated to any of the racks, it is also necessary to differentiate the storage sections for each type of pallet.

In order to make it easier to visualize all the sections and storage allocation zones described above, the scheme presented in Figure 15 was carried out.

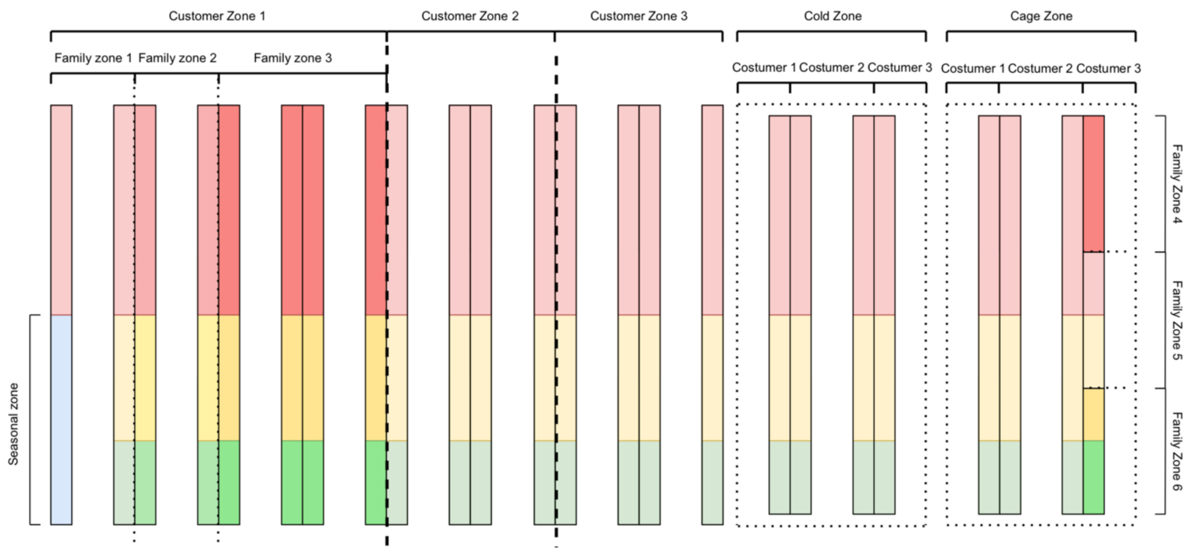

Figure 15 - Scheme of an example of a warehouse's layout.

This diagram represents just one example of a possible layout of a three-client warehouse with all the possible sections taken into consideration in this project.

4.2.3 Searching strategy for storage places

As explained in the previous topic, the strategy of only dividing the picking locations into customers and families was adopted. In the model proposed this division is not considered in the reserve places, as these are more flexible due to the availability of the places. Thus, together with the team, it was decided that a new approach would be taken into account - the search for an available storage location as close to the picking bin of the SKU in question as possible. This is quite important since it allows the company to optimize the replenishment of the picking locations by minimizing the movement times in this operation. Since as a general rule all products that are in reserve storage locations will be placed in picking locations before being shipped, it can be considered more important that the reserve storage locations be closer to the picking locations than closer to the output. This helps to improve the picking process and minimize its costs.

Thus, in the model developed, the aisle where picking is performed was taken into consideration as a parameter. Thus, it is intended that if an SKU that enters the warehouse has a picking location, it should preferably be allocated in that aisle.

4.2.4 Characterization of SKUs and storage locations

After dividing the warehouse into different sections and zones, it is possible to characterize each of the warehouse locations according to the various parameters taken into account. In addition, it is important to note that in order to be able to assign a warehouse location to an SKU, it is necessary to characterize all SKUs with those same parameters as well. In this way, it is possible to match the products with the locations according to the parameters they have in common.

It is also important to notice that the SKUs may also vary in weight and size, and as a result, each pallet of products will have specific values for these parameters. In the same way, the warehouse storage places can also variate in size and in the weight they can support.

Thus, after dividing the warehouse locations by areas, and also have the knowledge that each storage place may vary in the weight they can support and the size, it is possible to characterize each warehouse storage location with the following parameters:

- Size
- Weight
- Customer
- Family
- Aisle of picking
- Class turnover (A, B, C)
- Storage section

Note that pallet size is a parameter that greatly restricts the search done by the system, as storage locations vary a lot in size and not all pallets will fit in every location. One solution to facilitate standardization of dimensions would be to use only one type of pallet and control the height of each lot. This could be achieved by repalletizing the goods as it is done at Bosch or Parfois. Then it would be possible to have warehouse locations that are all the same size and eliminate size restrictions when allocating pallets to locations. However, due to the variety of customers and products in Rangel's warehouses, this is not an easy process. Considering the current reality, size should be considered as a parameter to take into account in the allocation restrictions

Since it will not always be possible to obtain perfectly sized storage locations for each SKU, and each warehouse has its rack dimensions, the following approach was taken into account. It is considered that the warehouse dimensions, although not uniform, are known and will be understood as standard levels. For example, the lowest level corresponds to size 1, the second lowest level to size 2, and so on. Assuming that each pallet that arrives at the warehouse has specific dimensions and assuming that the system knows them, it will assign the lowest possible standard size level to it. In this way, knowing the warehouse storage sizes, and knowing the size of the SKU in question, it is possible to parameterize the size of this same SKU with the lowest possible level, that is, the lowest dimension where this pallet fits (from the size 1 to the size X, being X the maximum number of size levels in that warehouse).

Taking Figure 16 to better explain what was described above: considering that in a warehouse there are four different sizes of storage places that vary in height (considering that within the same type of pallet the length and width remain the same): size 1 – 0,5 meters, size 2 - 1 meter, size 3 – 1,5 meters and size 4 – 2 meters. In this way, each size corresponds to one size level.

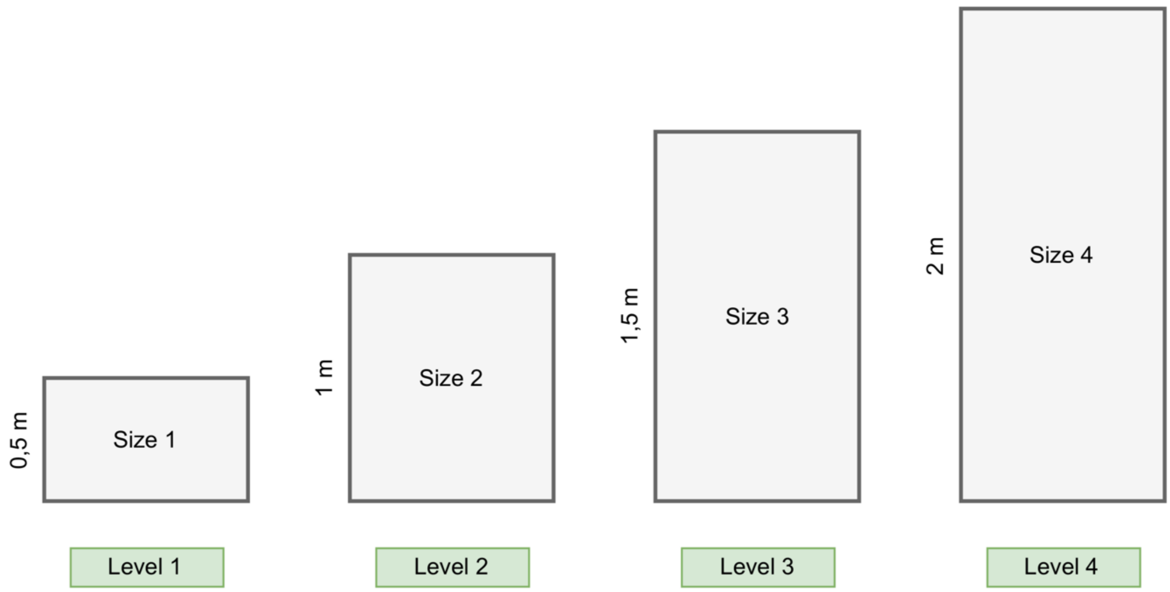

Figure 16 - Scheme of the possible different size levels of storage locations in a warehouse.

Then it was considered that the various SKUs will be associated with one of these 4 different standard levels. Considering that a pallet arrives at the warehouse with a height of 0,75 meters, it will be associated with the size level 2, since it is the lowest level where it fits. If there are no places available of that size, a storage place of size 3 will be assigned, once a place of size 1 is not adequate.

The same philosophy is adopted when it comes to the parameter of weight. Each warehouse location can support a maximum of a certain weight, and each SKU's weight is known. Thus, the system always preferentially associates the SKU with the lowest possible level. This method is adopted in order to optimize warehouse space in order not to occupy larger storage spaces that support greater weights with smaller or lighter products.

As for the client, family, and class turnover parameters, as described in the previous subchapter, these depend directly on the layout adopted. Thus, each location in the warehouse will correspond to a customer, a family, and a certain class. Likewise, each product will correspond to a customer, a family, and a turnover class

Finally, the warehouse is divided into storage sections and each SKU is destined for one of these. These storage sections, as mentioned before, can relate to a cage zone, a seasonal zone, or even a zone intended for a specific type of pallet.

Chaining sequences

It is important to highlight that in the first phase, the goal is to try to find the perfect match of an SKU with a storage location, that is, to match all the parameters previously described. However, due to the large inflow in the warehouse and since the availability of the storage locations is sometimes quite variable, this is not always possible. In this way, for parameters like size, weight, and class turnover a chaining sequence process is used, where when it is not possible to give a perfect match, these parameters suffer a sequence alteration.

Taking again the Example 1 previously described, when the storage places corresponding to the lowest size level for that SKU are all full, the next search will follow the chaining sequence that corresponds to the next bigger size level. Should be noted, that this chaining sequence is limited once it is not possible to search a storage place smaller than the actual product, just bigger ones. Again taking Example 1, in this case, the chaining sequence would be:

1. size 2 (perfect match)
2. size 3
3. size 4

Size 1 would not take part, once it’s smaller than the actual product.

Table 2 sums up all this information (assuming there are 4 different sizes in the warehouse). The first column represents the corresponding size of the SKU pallet in that warehouse and each row represents the sequence order for that size. Remember that no pallet can be allocated to a smaller location than this, therefore, the last pallet size (in this case size 4) only has one destinated storage size. st

Table 2 - Order of the chaining sequence of each size

	Size 1	Size 2	Size 3	Size 4
Size 1	1st	2nd	3rd	4th
Size 2	-	1st	2nd	3rd
Size 3	-	-	1st	2nd
Size 4	-	-	-	1st

The exact same process happens with the parameter of the weight. Of course, this chaining sequence always depends on the type of product it is being dealt with, each SKU will have its own size and weight sequences according to its parameters.

As for the class turnover parameter, it also has a chaining sequence in case there are no locations of that exact class turnover available. In the case of products with A class turnover, the chaining sequence follows the logic from higher turnover - to lower turnover: This makes sense once as it is intended that a product with the maximum class turnover should be in a place with the best possible accessibility. If it is not possible to allocate it to an A position, then the priority is to allocate it to a B position.

In the case of products with C class turnover, the chaining sequence follows the logic from the lowest turnover - to higher turnover. In the same way as before, if a product as has the lowest class turnover it is intended for it to stay in a storage place with the lowest class turnover possible.

Finally, if a product has a B class turnover, it was concluded that it would make sense to give priority to a class C storage place rather than a class A. This might be logical once there are fewer storage places of class A and they should be saved to the corresponded SKU. They only are not there is no other alternative. In this case, the sequence is:

Table 3 - Order of the chaining sequence of each class turnover

	A	B	C
A	1st	2nd	3rd
B	3rd	1st	2nd
C	3rd	2nd	1st

All this information is combined in Table 3. Where the first column represents the SKU's class turnover and each row represents the chaining sequence for each class turnover.

Finally for the remaining parameters: customer, family, and aisle of picking there are no chaining sequences associated with each one. If the perfect match is not found, the system will "switch off" that parameter and search outside of that zone. With regard to the relationship between these three parameters, since the warehouse is divided into customer and family areas, it was decided to give priority to customer zones first, then to family zones and only then to the picking aisle. This means that if the perfect math doesn't occur the system will "switch off" the aisle of the picking parameter and will try to find a place within the same family and customer. If there is still no match, then the system will "switch off" the family parameter and will search within the same customer but outside of that SKU's family zone.

All these alternatives, in case there is no perfect match, are sequenced together and their order of action will be explained and hopefully better understood in the next chapter through a flow chart.

4.3 Flow Chart

Gathering all the parameters and strategies to be adopted, the flowchart was designed to be read, traversed, and in it to have a solution for the allocation of an SKU that needs to be stored in the warehouse. The full flowchart can be found in Annex A.

The flowchart starts with the SKU entering the warehouse, then its barcode is scanned and the system is able to read all its information, as can be seen in Figure 17. It is assumed that the system contains every parameter regarding the SKUs and, in this way, it is possible to assign it to a warehouse location that matches the requirements of the product. So, the next steps of the flowchart show the questions that the system "asks" the product to help it get to the appropriate storage location.

The first triage begins with the blue rectangle, where the system limits the search to that SKU's storage section.

Then the second triage follows: does that SKU already have a picking bin? If the answer is yes, the search for the available place will also be conditioned by that SKU's picking bin. In this way, the system will follow the path that prioritizes the storage places within the aisle where the picking is done, as close to it as possible. If the answer is no, the system will go through the path where it follows other criteria that will be described further.

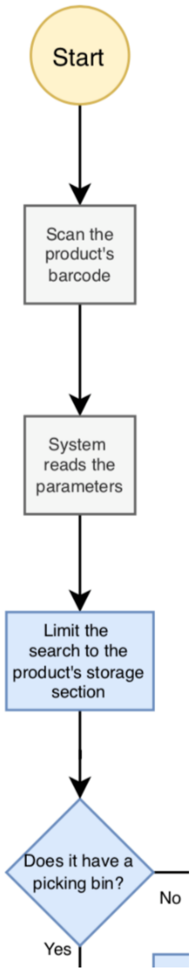

Figure 17 - Section 1 of the flowchart.

Then, following the path where there is a picking bin for that product, the limitation of the search continues in the following steps, where the range of options for storage places becomes more and more restricted. In these following steps, it is necessary to define the search criteria that the system will follow in the first phase. Initially, the system will try to find the perfect match, that is, an available place respecting all the characteristics of that SKU: the customer zone, the lowest possible weight and size level, the picking aisle, the family zone, and also the class turnover of that product, as seen in Figure 18.

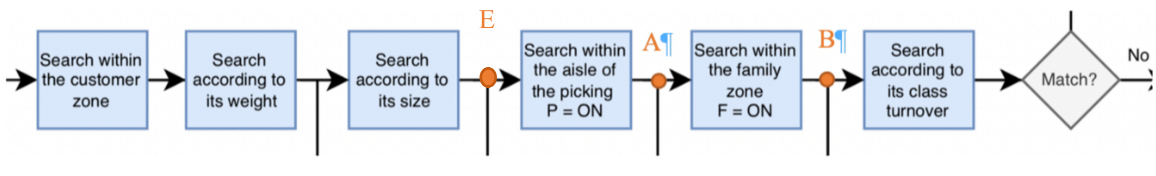

Figure 18 – Section 2 of the flowchart.

As mentioned before, it is important to notice that it is assumed that the system will indicate a storage place as close to the picking bin as possible. Therefore, it is important that, when programmed, the system is able to search from the closest storage place to the picking to the one further away. In fact, this model was thought in such a way that the system would search for an available place by going through each storage place in a specific order of zones. This order is based on the SKU's properties like the aisle of the picking bin, if existent, and the SKU's customer and family zones, so, in the model it is explained which priority locations this search is guided by. However, the model only limits the search to aisles or zones through the parameters associated with the SKUs. It is necessary to understand that the system has its own way of going through each warehouse storage location inside each zone. In this way, it is assumed that the system will always search for the closest open location to the picking bin within each limited zone. One method possible to adopt is the search method in "circle" used by Parfois described before. However, there could be other methods possible also, depending on the order in which the storage locations are sequenced in the actual system. For this model, it was simply assumed that the place that is suggested is the closest to the picking as possible; that is, the one that better optimizes the replenishment movements.

Then, after defining all the parameters, the question "Match?" appears in order to symbolize that a search is going to be performed with all the parameters defined before. If the perfect match occurs, the answer to the question is "yes" and the path in the flowchart continues going upwards where the system indicates the storage place where it was found. If the answer is "no", the flowchart continues to the right to section 3, Figure 19.

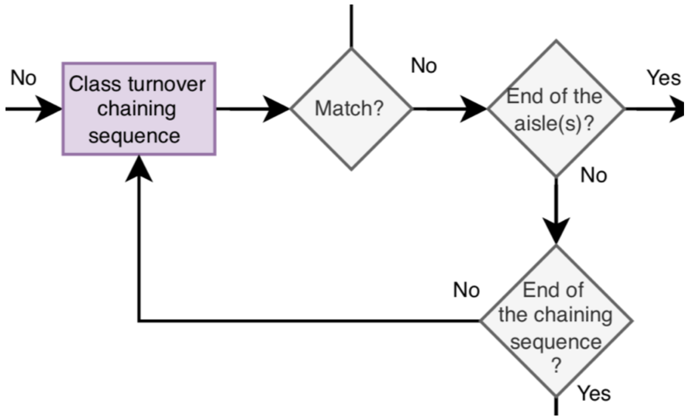

Figure 19 - Section 3 of the flowchart.

If the perfect match does not occur with all the "original" parameters of that SKU, it is necessary to perform a chaining sequence associated with one of these. As previously mentioned, it is intended to give priority to the picking aisle since it is considered to be one of the most important parameters that allow optimization of product replenishment times and movements. Thus, it is intended to continue the research in this same aisle. In order to optimize space, the parameters of weight and height are also maintained. And finally, in order to keep the warehouse organized by families, this parameter is also a priority.

The parameter of the class turnover is then chosen for the chaining sequence, allowing the search to be repeated for all of the same parameters while changing only this one.

So, observing again Table 3, the system will search according to the class turnover presented in the 2nd place.

Then, if the end of the aisle is reached, that sequence ends and the search moves to another section of the flowchart – section 5 in Figure 19 – that will be described later on.

Now, if the end of the aisle has still not been reached but arrives at the end of the chaining sequence in Table 3, the search moves on to section 4 in Figure 21, which will also be described later on.

If the end of the aisle and the end of the chaining sequence are not yet reached, then the sequence continues, moving to the 3rd position in Table 3. This continues until the chaining sequence or the aisle ends.

At this point in the flowchart, the entire family zone within the picking aisle has already been covered. However, that family zone could continue into the other aisles. If no location has been found in the picking aisle, then another parameter must suffer a chaining sequence. As the organization of the warehouse is by families and the optimization of space is considered very relevant, the variables corresponding to the family zone, size, and weight are chosen to be maintained. Thus, the search in the aisle of the picking is stopped by turning off this parameter, moving on to the other aisles to continue the search within that product’s family zone.

However, if the family zone is shorter than an aisle and the end of the product family zone is reached, the same criterion does not apply. Since there are no more zones for that family, it will be necessary to search for a location outside the family zone of that product. In this way, it is still possible to maintain the priority of the picking aisle for that product.

In order to better understand what was described in the last paragraphs, let's take Figure 20, with the possible five different arrangements of the families in the warehouse aisles. The coloured part represents the family zone of the SKU in question, with each colour referring to the type of class turnover. The non-coloured parts refer to the other family zones within the same customer. The green "X" represents the hypothetical picking place that will be considered in every one of the five different hypotheses.

Taking again Figure 19, after the chaining sequence is completed, and if there is still no match, in cases 1, 2, and 3 of Figure 20, the answer to the question "End of the aisle?" would be "yes" once their family zones fill completely all their picking aisles. In this way, the flowchart continues into Section 5, which will be described further on.

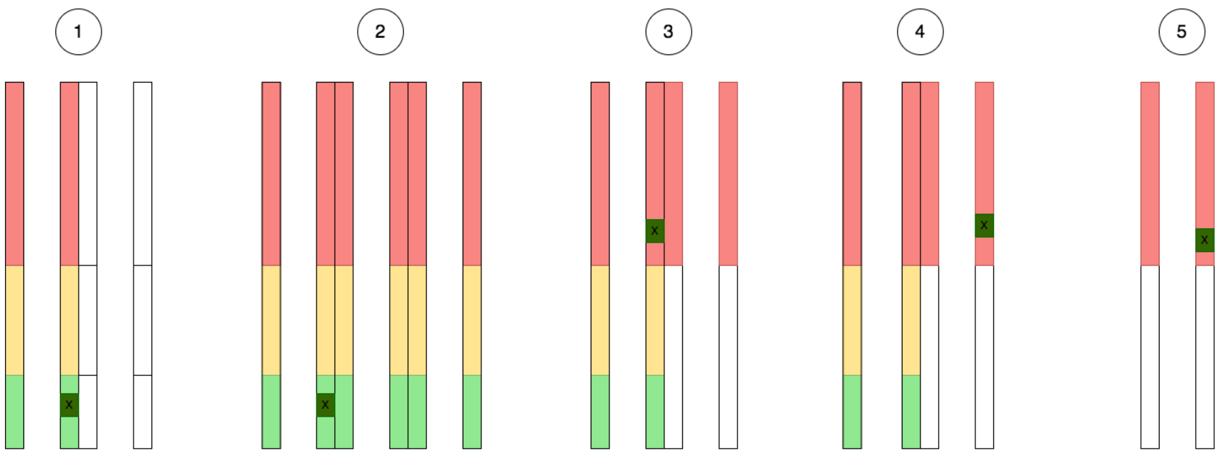

Figure 20 - Different types of customer zone and family zone layouts.

In cases 4 and 5 of Figure 20, the family zone doesn't completely fill the picking aisle, so the flowchart path continues into Section 4 in Figure 21. In this section, it is possible to follow 3 different paths.

Starting with the first one, referring to case 4 of figure 20, the end of the family zone in the picking aisle is reached, but the family zone continues in the next aisle. So in Figure 21, the answer to the question "End of the family?" is "no". It is necessary to give priority to the family zone over the rest of the picking aisle. Therefore, "P = Off" is done in order to indicate that the search will be done outside the picking aisle. Then the system will "search the rest of the family aisles for the closest location to the picking aisle".

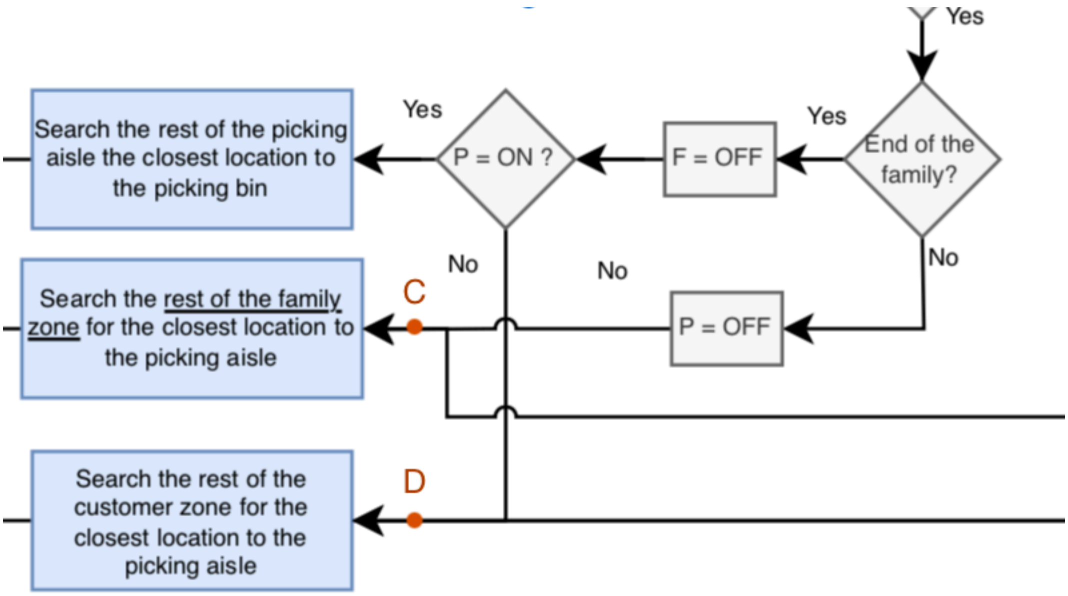

Figure 21 - Section 4 of the flowchart

This arrow will connect directly to point A, of Section 2, in figure 18. That is, keeping all the parameters defined before, except those that were indicated to be changed (search outside the picking aisle), a new search will be performed. Thus, it is intended that the system performs a new search within the entire family area (except for the picking aisle), restarting the chaining sequence of the class turnover for that area.

It should be noted that throughout the flowchart it is assumed that the searches are performed according to the parameters last defined, which, if they do not change along the way, they are assumed to remain the same.

Moving on to the second path, observing once again Figure 20, now looking at Case 5, the end of the family zone has been reached without finding an available storage place. Thus, it will be necessary to search outside the family zone of that product. However, the priority of the picking aisle is maintained since it has not yet been traversed until the end. Since "P=on?" is still true, the system "searches the rest of the picking aisle for the closest location to the picking bin". This arrow will then connect to point B from Section 2 of Figure 18, and a new search will then be performed.

Basically, the difference between cases 4 and 5 of Figure 20 is related to the question of whether or not the end of the family zone has been reached. This is what will differentiate the path to follow since the priorities change.

Further on, in case 4, it is presented the third path of this section, when the search is being performed outside of the picking aisle but still in the same family zone. The path will end up again with the question "P = on?" in Figure 21. However, in this case, the answer is "no", so the flowchart will follow a different path. The system will now search outside of the family zone: "Search the rest of the customer zone for the closest location to the picking aisle". This arrow will then connect to point A, from Section 2, of Figure 18 and a new search will be performed.

Moving on to section 5 of the flowchart, Figure 22. Remember that to get here, the answer to the question "End of the aisle?" in Figure 19 must be "yes". So, if the previous search was still in the picking aisle, then "P = off" since it has now reached the end of the aisle (these are the previously referred cases 1, 2, and 3 in Figure 20). If the search was already going ahead and "P=off", this step is simply skipped.

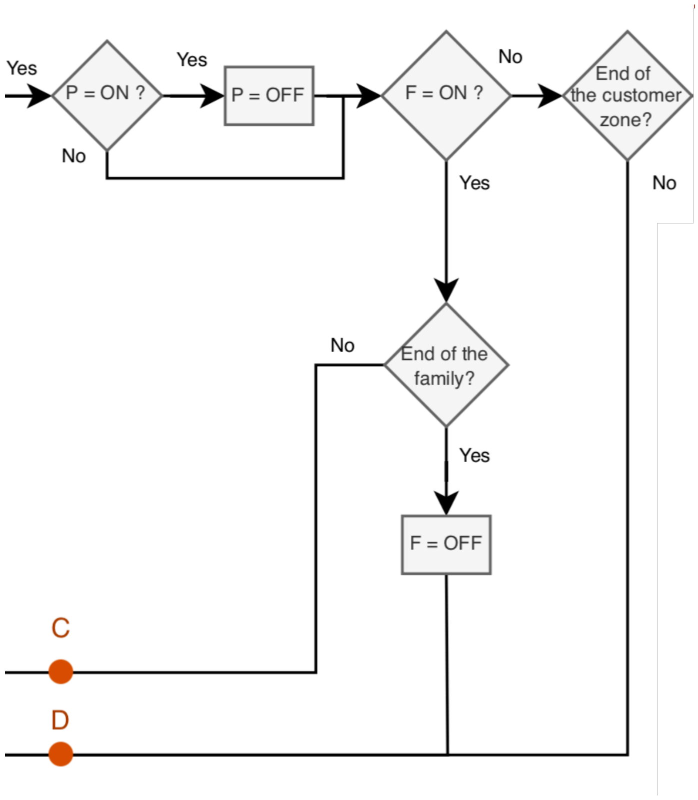

Figure 22 - Section 5 of the flowchart.

Next, the question "F = On?" is asked to verify if the search is still within the family zone. If yes, it is then checked if this search has now reached its end after the last step. If yes, then "F = off" and Point D in Figure 22 will connect to Point D in Figure 21 and, as described above, a search will take place outside the product family zone. This is case 1 in figure 20.

If the answer to the last question is "no," then the search inside the family zone continues, although outside the picking aisle, which could be cases 2 and 3 in Figure 20. Point C in Figure 22 connects to point C in Figure 21.

When the search was already being conducted outside of the family zone and the question "F=On?" in Figure 22 is reached, then the answer is "No" and the question "End of the customer zone?" is asked. If the system hasn't gone through all the places within that customer, for the parameters defined before, then the answer to the question is "No". The end of the customer zone has not been reached yet. In this case, the search continues through point D as well. This goes on until the end of the customer zone is reached. When it reaches it, the flowchart continues to section 6 in Figure 23.

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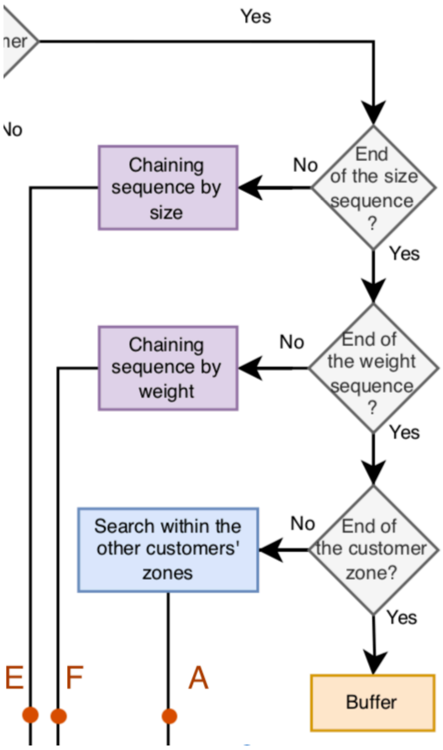

Figure 23 - Section 6 of the flowchart.

After getting to the end of the customer's zone and still not being successful, it's important to use the size and weight chaining sequences in this order.

In the context of a warehouse, at this stage, it is considered more relevant to give priority to the organization by customer zones in order to better organize the orders received by the warehouse. In this way, it is decided to change the size parameter while maintaining all other initial ones. In this way, the system helps maintain the division of the warehouse into customer zones and will search for more available places corresponding to the second level of sizes.

Thus, starting the chaining sequence of size, according to the example in Table 2, the system will now search for a location corresponding to priority order 2. In this way, Point E in Figure 23 will connect to Point E in Figure 18. Here all the initial parameters of the SKU are reset. Thus, this new search is performed according to all the initial parameters, with the exception of the new size parameter. This is, the system performs a new search within that family zone, within the picking aisle, although with a different parameter of size. Thus, the flowchart follows exactly the path that has been traversed so far with this new parameter.

If there are no places available for that size, then a new chaining sequence for the size is performed. This is done until the last possible size level is reached.

If the end of the storage sizes is reached without finding a free storage place, the same process takes place for the weight. Where point F in Figure 23 connects to point F in Figure 18.

Finally, if this entire path is traversed for all weights and all sizes following the chaining sequences of the parameters of this SKU for that customer zone, it means that there are no available places for that product in the entire customer zone. In this case, it will be necessary to search outside this zone. If this occurs, Point A in Figure 23 will connect to Point A in Figure 18. Thus, the search according to the class turnover will proceed once again, following the remaining path in the flowchart described above. However, now the customer zone parameter is turned off and the size and weight parameters are reset to the ones initially considered. At this stage, the parameter for the family zone is also switched off since it is not considered relevant to maintain the family criterion in the search outside of the customer zone since the families of different customers are also different.

If the system still does not find an empty storage place, it means that all the places that could possibly be used for that product are full in the entire warehouse. Therefore, a storage buffer will be needed.

However, this whole process described above is for the case where the SKU in question has a picking bin. If it is a product that does not have a picking location, the method used by the system must be different since the chosen location is not conditioned by any picking location, and resuming Figure 17, the flowchart must follow the path of "No." Thus, the search performed by the system will not be done considering the parameter of the picking aisle.

Observing now Figure 24, it is possible to verify the parameters by which the search will be guided, being these the same as the path previously described with the omission of the picking aisle parameter. This is because no priority will be given to any of the aisles in particular. Since the SKU has no picking location, it is not necessary for it to be allocated to a specific aisle within the family itself.

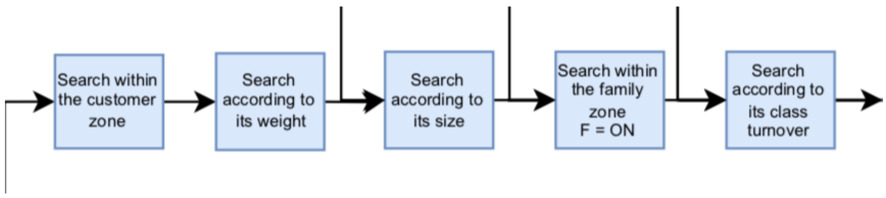

Figure 24 - Section 7 of the flowchart.

So, since the search made by the system does not give priority to any specific aisle, the first search it makes is performed on the entire family zone. Observing Figure 25, it is possible to understand the method used by the system.

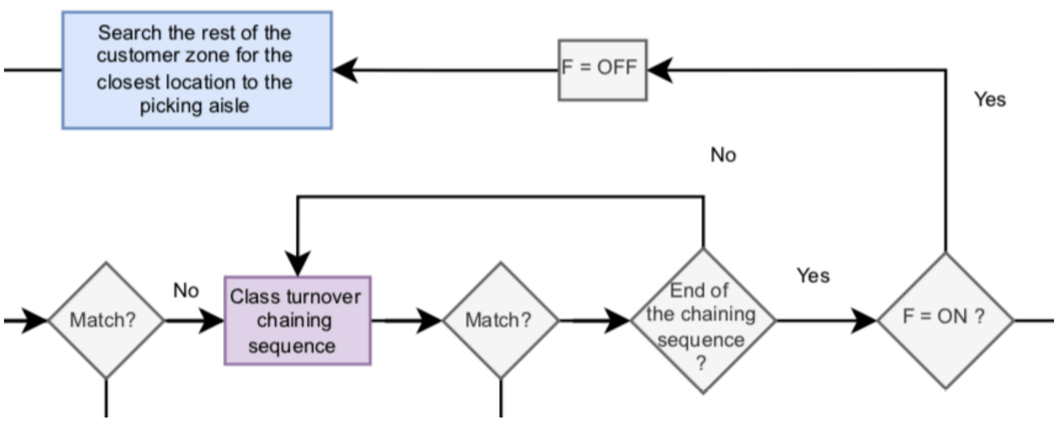

Figure 25 - Section 8 of the flowchart.

Once the search is done for the entire family zone, reaching the end of the chaining sequence for the class turnover means that it reaches the end of the family zone of the product. If this happens, "F=off" and a new search is performed on the locations outside the family zone.

If "F=off", the answer to the question will be "No", which means that the zone outside the family for that customer has also been walked through. So, as with the previous route, it will be necessary to search outside the customer zone. From here onwards, the flowchart path will be exactly the same as described above in the case of bin picking.

4.4 User's Manual

As previously mentioned, the allocation model designed in the previous topic is a model based on the allocation needs of Rangel's warehouses. All decisions about strategies and priorities to be adopted were made based on the current needs of warehouse operations and within a work team. Thus, the new model takes into account most of the parameters already used in the current model since they cover the most important characteristics to be considered. So, in this topic, it will be shown how most of the new model's parameters can be adapted to the Rangel ICOL system, as well as some changes that might be needed because of the new strategy.

Recalling Figures 5 and 6 of Chapter 3, now replicated in Figures 26 and 27, it is possible to observe, once again, the general and the ADE parameterization of the warehouse SKUs, respectively. Starting with Figure 26, it is possible to observe innumerable properties that must be filled, many of which do not concern the allocation issue, so in this chapter, the attention will be focused more on the properties that are involved in the model. In the place of "Código Produto" (product code), should be inserted the SKU's code that is associated internally with several specific and fixed properties of this last one, such as customer, size, weight, and so on. This way, through this code, the system knows the customer parameter. Below, it is also possible to associate this SKU with the product family.

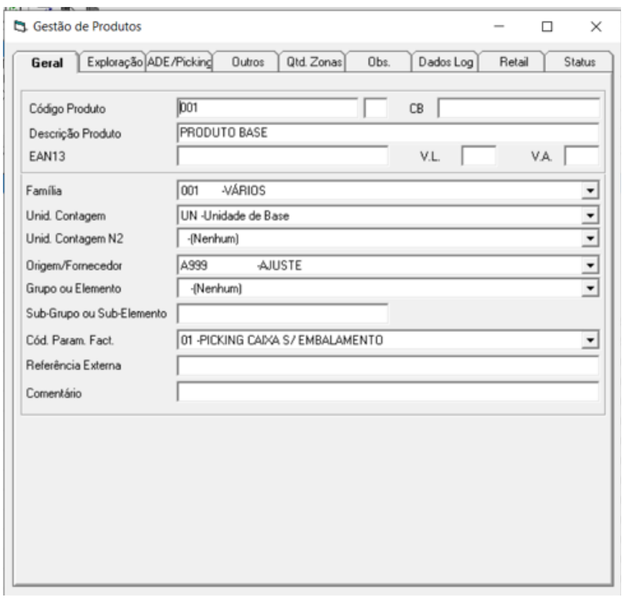

Figure 26 - General parametrization for SKUs.

Now in Figure 27, on the second line, it is also possible to associate the SKU with a storage section, followed by the class turnover.

On the fourth line, it is possible to observe the "Classe de Afetação", the assignment class. This class is currently used in order to define a property, to which it is also intended to assign a certain order of priority. Thus, in the new model, it is suggested that this parameter concerns the size levels.

In the same way, the warehouse locations are characterized. Recalling Figure 7, replicated in Figure 27, it is possible to observe the ADE parameterization of the warehouse locations. In the eighth line, where it reads "Reserva Depositante", it is possible to indicate the customer for whom it is wanted to book that storage location. Next, on line 10, the family it is intended to associate with is also placed. The next line indicates the storage section, followed by the turnover class and assignment class.

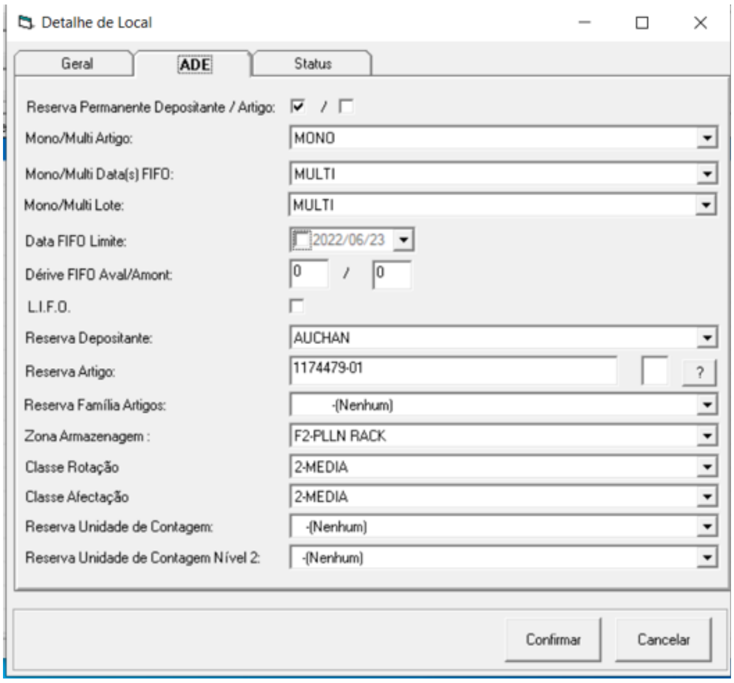

Figure 27 - ADE parameters for the storage location.

Two parameters remain to be associated: weight and the aisle of picking. It is suggested that since these do not exist in the current system, they be added to the characterization of both SKUs and warehouse locations.

Although changing the way products are characterized is not so easy and implies serious changes, it is considered relevant, taking into consideration the new strategy adopted. Once the proximity of the products to their picking bins has been taken into account, it is necessary for the system to always be up to date with the picking location of each of the warehouse's SKU's.

However, adding two new parameters can be too much. When it comes to the weight, it may be possible to combine two parameters into one. Thus, if it makes sense in a certain warehouse for the type of products in stock, each size level can correspond to a weight level, and the assignment class becomes a kind of combination of these two variables. However, this only makes sense and only optimizes the space if the variations of density of the products are not too distinct.

It is also important to note that for the size, weight, and class turnover parameters of each SKU, it is also necessary to define the order of the chaining sequence. This change is also suggested since there is currently no room for this in the current system.

Finally, it is important to highlight that despite the existence of all these parameters, it does not mean that all warehouses have to consider them in their system. As mentioned before, if, in a certain warehouse, it does not make sense to consider the turnover class of a product, this variable can easily be eliminated. This is done by assigning all SKUs an average class turnover level (class B, for example) as well as the storage locations so that the products are equally distributed throughout the warehouse. The same happens with the product family parameter, assigning all products and all locations to the same family within a customer zone.

5 Conclusion

This project, developed in the scope of the curricular internship and Master's thesis, arose from the need that Rangel had to reformulate the SKU storage strategy in its warehouses. At the moment, the company doesn't have a defined allocation strategy, usually leaving it to the operator's criteria, which is not always the most efficient. Thus, based on Rangel's needs, studying the various possible allocation strategies as well as observing other companies in the same sector, it was possible to create a new allocation method that best suits the company and intends to optimize its spaces and operations.

Throughout this study, as the new allocation strategies were developed, it was concluded that a number of parameters needed to be considered in the system. These parameters are associated with SKUs and, in turn, with storage locations. In this way, from these as well as with the help of the proposed criteria, it will be possible to match the SKUs to certain storage locations.

Size and weight levels are two necessary parameters to be taken into account. By associating each pallet, as well as each storage location, to size and weight levels, it is possible to match them. In the case of the perfect match not occurring, it is intended to give priority to the next lower possible levels, with the aim of trying to fill the smallest places as much as possible. This prevents large pallets or pallets with higher loads, which have fewer allocation options, from not having suitable places to be allocated. In this way, the method proposed tries to increase the area available for storage, optimizing warehouse spaces to the maximum.

Furthermore, it is considered very important to maintain the division of the warehouse by customers, as it is already done in Rangel’s warehouses as well as in two of the warehouses studied, making this another essential parameter in the system. Furthermore, it is also considered beneficial to take into account the product’s family parameter, in order to maintain the division of spaces within each customer by family type. This can be an added value to the outbound processes since it aims to reduce the picking times. This is because the same customers will be those who order products of the same type, that is, from the same families. This means that the orders made by them will certainly have products belonging to the same families.

This new model also takes into account the hypothesis of considering a layout organization based on the class turnover of products. This is the Class-Based Strategy studied previously. Given the diversity of SKUs in some of Rangel's warehouses, as well as their possible different output frequency, it is considered an added value to have this parameter in the system since it would be a crucial point in reducing the overall picking times. To obtain this, a detailed study of the SKU's frequency of exit from the warehouse is necessary, as well as a good organization of its layout. This strategy tends to reduce significantly picking distances, and in turn, the respective processing times, since it is intended that products with higher turnover are allocated to storage locations closer to the output.

In addition, throughout this work, and similarly to what happens at the Parfois warehouse, it also proved to be important to create a strategy to optimize product replenishment, thus creating a new parameter in the system: the aisle of picking. This parameter aims to give priority to free locations in the same aisle where the picking of the SKU in question is done. This method has the goal of reducing replenishment distances as well as times by bringing reserve locations as close as possible to their picking locations.

In conclusion, the method proposed aims to bring to the company several gains, such as a reduction in processing times, specifically picking and replenishment times, as well as better layout organization and better use of its storage locations.

When this project was presented, 3 major objectives were proposed:

Studying and recognizing the strategies and rules to obtain a bigger operational efficiency in the inbound and outbound processes.

Define the most relevant parameters and production of a flowchart with requirements/conditions vs. strategies.

Creation of a support document for the configuration of the functionality in Rangel's WMS system, as a user manual.

It is considered that these objectives were achieved throughout three different phases. In the first phase, a detailed study of the allocation strategies used in warehouses was performed. This study sought to understand which strategies intend to optimize the inbound and outbound processes. For this, a theoretical study, based on the literature, of all the operations of a warehouse was performed in order to be able to understand all the operations that are involved. In addition, the allocation strategies generally used and the requirements associated with them were studied. Afterwards, a practical study was performed, going through the recognition of the operations in the several Rangel warehouses as well as the needs of each one of them. Finally, other companies in the same sector were also visited, in order to understand what kinds of strategies are used in those warehouses. Thus, in the case studies performed, in addition to describing some of the operations performed, focus was also given to the understanding of the warehouse layout, as well as the allocation strategies used and how they fit these operations.

In the second phase, Rangel's operations and their needs were better understood. This way, based on the strategies studied, it was possible to understand which ones would apply to the company's reality. The methods and parameters considered relevant were then gathered and these were assigned orders of priority. Finally, the newly proposed method was illustrated through a flowchart, where it is possible to observe the "paths" travelled by the system when looking for a storage location for a given product, adaptable to several different situations.

Finally, in the third phase, all the parameters necessary for the new strategy to work and how they can be adapted to the parameters of characterization of the SKUs and the storage locations in the Rangel ICOL system were gathered. It was also proposed the creation of new parameters such as the aisle of picking, as well as the degradation system - chaining sequence, for some of the parameters, in order to manage its orders of priority.

Throughout this work, several obstacles were encountered, particularly the fact that this is a rather abstract subject that involves many variables and that it varies greatly from case to case. There is no "right" allocation strategy, only the closest to the optimal one given the circumstances. Another obstacle was encountered while the observation of other companies' strategies. Although certain strategies work very well for a given warehouse, this does not mean that they will work for another, which often makes it difficult to compare them. The same happens when thinking about strategies that in theory seem very plausible but do not work in the most efficient way when applied in reality. It is also a very broad topic that involves several factors and, therefore, several departments within a warehouse. So, as observed, each company chooses a strategy and adapts it as much as possible to its reality. It is not an exact science, so there is always room for improvement, especially once implemented.

6 Future Works

Following the last chapter, a simulation of the new proposed method is considered relevant as future work. This step aims to verify the expected gains that the company will have with the project and quantify them in order to prove its viability.

Later on, the programming of the new model in the ICOL system, adapting the new strategies and parameters to it, is expected. Then, the implementation of this model in one of the warehouses in test mode is important in order to verify the improvements in operation times and the detection of possible improvements in the system. As previously mentioned, it is necessary to perform a study of the products' turnover in the warehouse and correspond them to classes, as well as group them by product family groups. Following this, a reorganisation of the warehouse layout is also required.

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ANNEX A: Flowchart