Bachelor Thesis

Industrial Engineering and Management

Improving Order Picking Efficiency in EvW's Warehouse

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e van wijk FORWARDING

Management Summary

After the departure of a big client in the warehouse, many free spaces were created. The warehouse reacted to this change by randomly storing inventory, trying to fill the void of the previous client. As a result, products that were highly compatible with each other were stored far away from each other and products that were fast-moving (ordered a lot) were placed far away from the I/O point. Thus, long travel distances occurred when picking orders, especially in zones A, F, G, H, and I (different storage areas in the warehouse) of the warehouse.

E. van Wijk Forwarding (EvW) wanted a new storage assignment policy for the aforementioned zones to decrease the distance traveled when picking orders by identifying the fast-moving products and storing them closer to the I/O point, and storing products that are frequently ordered together closer to each other. Thus, the main research question of this thesis is:

How can a storage assignment policy improve the order-picking efficiency in EvW's warehouse?

This question was tackled by first researching basic warehouse principles such as the functions of a warehouse and the order-picking process. Then, research was done on storage assignment policies to find the policies that decreased the most travel distance when picking orders. The two storage policies chosen were the Cube per Order Index (COI) and the Order Oriented Slotting (OOS) as they were well-known to decrease travel distances in different order picking scenarios (Schuur, 2015). Moreover, common strategies that reduce the workload of order picking were studied such as the forward-reserve storage strategy which divided a rack into a pick and bulk area.

After gaining more knowledge on the assignment from the literature, the current situation of the warehouse was studied by analyzing the current order picking process and gaining a deeper understanding of the stock stored in zones A, F, G, H, and I in the warehouse. Also, the information required to create and implement the COI and OOS storage policies was extracted from the company by studying the order history from the Warehouse Management System (WMS).

Order	Zone	Distance Traveled (Current Storage)	Distance Traveled (New Storage)	Difference	Difference (%) per Order
1	A	50 meters	30 meters	20 meters	40%
2	A	54 meters	34 meters	20 meters	37.04%
3	A	44 meters	32 meters	12 meters	27.27%
4	A	130 meters	50 meters	80 meters	61.54%
5	A	60 meters	54 meters	6 meters	10%
6	A	44 meters	38 meters	6 meters	13.64%
7	F	167 meters	101 meters	66 meters	39.52%
Total	-	549 meters	339 meters	210 meters	38.25%

Table i - Total Distance Traveled Comparison

Based on the data found, the COI and OOS storage assignment policies were created and implemented in the warehouse. The new storage assignment policy for zone A combined the COI and OOS storage strategies. However, the new storage assignment policy for zones F, G, H, and I used only a COI policy as the products stored in these zones were only single command orders. When testing the effectiveness of the new storage policies on these zones, the total distance traveled when picking a series of large orders was calculated and compared against the current layout. Table i shows a list of orders, each belonging to a different zone. As can be seen in the table, the new storage policies for each of the zones result in a decrease in the distance traveled. All in all, the total improvement for these seven orders was 38.25% when using the new storage assignment policies since lower travel distances were realized. This proved that the new storage locations could potentially perform better than the current ones.

Furthermore, this research is the starting point for EvW to increase the efficiency of its warehouse. A lot has been done in this thesis with the time given, but it also shows that more can be done in the future. A first recommendation would be to increase the scope of the study by including more zones. Zone B, in particular, is an interesting starting point since it is also used to store e-commerce products. Using both zones A and B to create an efficient order picking layout for all e-commerce clients can be an exciting study in the future. Another recommendation would be to increase the time frame used when analyzing the order history on the WMS. When extracting company data for the COI storage policy, April was taken as a starting point since that was when the big client had left the warehouse. Including more months in the analysis could produce more accurate findings. In addition, when comparing the new and old layouts a return routing policy was used. In the future, other routing policies can be experimented with to see how the results would change. Moreover, the warehouse sketch drawn in Excel was a very simple version of the warehouse. Creating a more complex sketch to calculate the distance traveled more accurately can be an interesting point of focus in the future.

It is up to the Managing Director, Milou Meijer, and the Warehouse Manager, Henk Brilhuis, to find someone suitable to implement these recommendations in the warehouse. Firstly, if someone from within the company is willing to explore these ideas further, then they have someone who is reliable and has a good knowledge of the problem and the company to complete the research and implement the storage assignment policies in the whole warehouse. Another option would be to get another student who is willing to build on this research by investigating more zones, using a longer time frame, and creating a more complex drawing of the warehouse to calculate the distance traveled.

Finally, the proposed storage assignment policies can convince the warehouse workers that a more efficient method of working is possible in terms of their order picking process. Moreover, when implemented, this can safeguard the company's reputation by providing timely/fast services to its customer base. Table ii below shows a roadmap for EvW on what the next steps are to continue working on this project.

	1.5 months	3 months	6 months	12 months
Zones	Add zone B	Test half of the warehouse	Test the whole warehouse	-
Time-frame	In the COI policy, start from January instead of April	For all order history analyses, take 1 year as a time frame	-	-
Assumptions and Limitations	Create distances for different slot locations A, B, C, and D	Create a limit to the number of e-commerce products that can be picked in one trip	-	Create a more complex drawing of the warehouse to calculate the distance traveled more accurately
Implementation	-	Implement the new storage assignment policy in zone B	Implement the new storage policy on half of the warehouse	Implement the new storage assignment policy in the whole warehouse.

Table ii - Roadmap

Preface

Dear reader,

In front of you lies my Bachelor's Thesis assignment, which endeavors to create a new storage assignment policy in E. van Wijk Forwarding’s warehouse to decrease the distance traveled when picking orders.

I would like to thank E. van Wijk Forwarding for allowing me to execute my bachelor thesis assignment at their company. I would also like to give a special thanks to my first company supervisor, Milou Meijer who helped me throughout the whole journey and always made time for me when I needed it. I would also like to thank my second company supervisor Henk Brilhuis for his daily support and for guiding me during the whole process. Furthermore, I would like to thank all of the employees at the company who were always there for me whenever I needed help and made me feel comfortable to be their colleague during this time.

Next, I would like to thank my first UT supervisor Lin Xie for her constant feedback, guidance, and support. In addition, I would like to thank my second supervisor Peter Schuur who supervised me as if he was my first supervisor. This thesis would not be possible without him since he gave me the constant feedback I needed to complete this report. I learned a lot from his experience in this field and I enjoyed the frequent meetings we had together.

Last but not least, I would like to thank my friends and family who were right behind my back from the first day. Their constant cheering and support are the reason I was able to finish this bachelor thesis assignment.

I hope you enjoy reading my thesis!

Youssef Tantawy,
September 2024

Table of Contents

1. Introduction

This section briefly introduces the thesis assignment by presenting information about the company and describing the current problem. In addition, an overview of the methodologies needed to solve the problem is given. Section 1.1 provides a background on the company, section 1.2 explains the current problem, section 1.3 illustrates the research objectives, section 1.4 describes the research methodology, section 1.5 states the research questions, and section 1.6 presents the research design.

1.1 Company Background

The E. van Wijk Group is divided into three sub-companies: E. van Wijk Logistics, E. van Wijk Forwarding, and E. van Wijk Real Estate. This thesis is done at E. van Wijk Forwarding (EvW), which is composed of six logistics companies all operating in Almelo: Twentepoort Logistics, Twentrex, Cargorilla Logistics, Himex Logistics, RUGO Logistics, and TwenPack (Twentepoort Logistiek BV, 2023). Each of the six companies has its specialization. For example, Twenpack specializes in e-commerce fulfillment, and RUGO in international transport (Twentepoort Logistiek BV, 2023). A forwarding company or a freight forwarder is seen as the intermediary between customers and the services that move the cargo to ensure that the product being shipped reaches its final destination (Crowley, 2023). This means that forwarding companies usually do not own transportation assets and do not transport themselves, thus their goal is to use their network to find a carrier that offers the best balance between cost, speed, and reliability for their customers (Crowley, 2023). In addition, EvW Forwarding, like any forwarding company, stores inventory for its clients in its warehouse, and this is one of its main revenue streams. This research focuses on EvW's warehouse, which generates about 10% of its total revenue. Moreover, a vital aspect of a freight forwarder is that they can simplify the burdens of international transport by shipping through their own bills, providing delivery documents, having the most recent information on customs regulations, handling customs clearance, and having trusted relationships in other countries (Crowley, 2023).

1.2 Problem Identification

Before the start of this assignment, a major client that occupied a large part of the warehouse had just left. This resulted in a change of storage compared to what was previously done. The products are now scattered all over the warehouse, freely occupying space with no real need to increase space utilization. The warehouse manager believes that order picking takes a long time since the inventory is scattered all over the warehouse and there is a lot of traveling done. In addition, the warehouse workers do not use a storage assignment policy to store their products. The current storage method is a random one based on gut feeling and experience. A pallet load, containing a product is usually given a location based on height requirements (if the location can take the height of the pallet load) or where similar products belonging to the same client are stored. The problem with randomly storing products in the warehouse is that large distances are traveled when picking orders (De Koster et al., 2006). This is because the fastest moving products (most selling) are not identified and placed in close locations near the dock doors, and products that are ordered together a lot are not identified and stored close to each other.

1.2.1 Core Problem

This section presents a problem cluster to identify the core and action problems and depicts how the problems are related to each other.

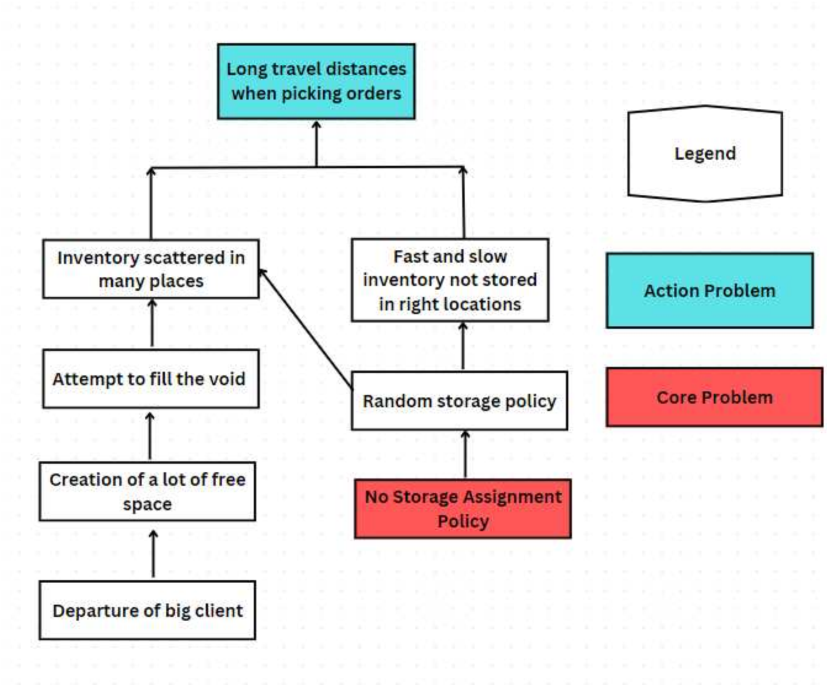


Figure 1.2 - Problem Cluster

Looking at Figure 1.2, the problem cluster is presented. Beginning with the left-hand side, the departure of their client caused many free spaces in the warehouse. The reaction of the warehouse workers to this change was a more flexible and free way of storing, making them try to fill the void of the previous client. By doing this, the current inventory is spread out in different places, meaning more distance is traveled when picking orders. On the other side, the effects of the lack of a storage assignment policy in the warehouse are shown. A lack of a storage assignment policy results in random storing, based on gut feeling and experience. The problem with this is that fast movers can be stored further away from the dock doors, while slow movers can be stored near the dock doors. In addition, the lack of a storage assignment policy does not consider frequently occurring orders and products that are frequently ordered together. These problems create long travel distances when picking orders.

The absence of a storage assignment policy is the core problem because it leads to random storing creating large travel distances when picking orders. Furthermore, according to Heerkens and Van Winden's (2017) core problem criteria, the absence of a storage assignment policy is a valid core problem since it has no direct cause, it is influenceable, and goes furthest back in the problem-relationship chain. A problem such as the departure of a previous client cannot be a core problem since it cannot be influenced, although it meets all other criteria of Heerkens and van Winden (2017). The following section describes the action problem: long travel distances, highlighted in blue in the problem cluster.

1.2.2 Action Problem

A 'norm' is a favorable situation or position one would like to be in. The 'reality' is the current situation that needs to be changed to reach that norm. An action problem is a problem where the desired norm does not meet the current reality; a discrepancy between the two (Heerkens and van Winden, 2017). EvW's current reality is that they have no storage assignment policy. The norm they would like to reach is to implement a storage assignment policy that identifies fast movers as well as popular and reoccurring orders and stores them together closer to the dock doors to decrease travel distance.

1.3 Research Objectives

The research objective is to decrease the distance traveled when picking orders in EvW's warehouse by creating a new storage assignment policy. To effectively test the results of this change, the distance it takes to retrieve a set of orders is calculated, using the new storage assignment policy, and is compared to the old/current storage assignment policy.

1.3.1 Deliverables

The deliverables of this thesis assignment are listed below:

1. A new storage assignment policy: products are stored in new locations.
2. Decrease in the distance traveled.

1.3.2 Reliability and Validity

According to Saunders et al., (2018), reliability and validity are two important aspects when assessing the quality of research. Reliability refers to the consistency of research. If a certain research is repeated, the same results should be achieved (Saunders et al., 2018). Reliability can be achieved by simply extracting the same data, implementing it, and considering the same KPIs, and the same results should be found if the research were to be carried out again by a different researcher. In addition, reliability can be achieved by standardizing the procedures done throughout the project. For example, when direct data is gathered from interviews, the same structured questions could be asked to different workers in the warehouse to ensure consistency in the methodology. Also, a frequent threat is the 'participation error', which is any factor that could change a participant's performance (Saunders et al. 2018). To avoid this threat, questions can be asked at a standard time of the day, to all workers, that is for example not close to or during their lunchtime, such that they are not affected by different times per day, and they are not asked during a sensitive time, such as their break. On the other hand, validity refers to using appropriate methods to measure the intended phenomenon, accurately assessing results, and generalizing findings (Saunders et al., 2018). In addition, the data can be validated by observing if what is happening in reality, in the warehouse, is the same as what is being described in the interviews. Coming back to reliability, one can use the 'triangulation' method as mentioned in the book of Saunders et al., (2018) which is to use two or more independent sources to verify if data, in a specific field of research, is valid or not. For example, when asking the warehouse workers where fast and slow-moving inventory should be stored, one can also refer to literature online to validate this data.

1.3.3 Scope and Limitations

The main scope of this assignment is EvW's warehouse and the inventory in it. Changing the layout of the warehouse is not in the scope. For example, more racks cannot be added, they cannot be made narrower, or wider. In addition, different machines cannot be provided or used, and the warehouse size cannot be altered. Furthermore, the new storage assignment policy uses data on only a few products in the warehouse and implements the change on only a few zones in the warehouse. These products are mostly the ones belonging to e-commerce clients in zone A of the warehouse since this zone is currently organized inefficiently and management perceives large improvements in terms of the distance traveled and throughput time. In addition, the client Pentair is another focus, which has products belonging to zones F, G, H, and I. These zones and the products belonging in them are described in more detail in section 3.

There are also limitations and constraints to this project. For example, there exist some constraints in terms of how the pallets can be stored in the warehouse. Heavy items must always be stored as low as possible on the racks, mainly at the floor level. In addition, low-weight products usually go higher up in the racks. Also, only creating a storage assignment policy for a few zones in the warehouse is a limitation since the storage policy is not implemented for other zones and products. This causes higher travel distances in the zones that are left out. Only a few zones are focused on because of the time constraint of this thesis assignment. Implementing the storage assignment policy on all of the warehouse would be too big of an assignment given the time requirements. In addition, focusing on a small part of the warehouse first is advantageous, because if the new storage assignment policy proves to be more efficient, then it can be implemented in the rest of the warehouse, but if it is not, then things can go back to the way they were without having changed too much in the warehouse.

1.4 Research Methodology

After considering several problem-solving approaches, the Managerial Problem Solving Method (MPSM) is seen as the best-fitting approach to solve the action problem due to its relevant problem-solving approach. The MPSM consists of 7 phases, Defining the problem, Formulating the approach, Analysing the problem, Formulating (alternative) solutions, Choosing a solution, Implementing the solution, and Evaluating the solution (Heerkens and van Winden, 2017). Before the action problem can be solved, small knowledge problems need to be addressed. These research questions are listed in section 1.5. The methodology to solve these questions is using the research cycle. Thus, in every phase of the MPSM, the research cycle is used simultaneously to acquire the knowledge needed to solve the action problem. Table 1.1 displays how each step of the MPSM is used.

MPSM Phase	Chapter
1. Defining the problem	Chapter 1 (Introduction)
2. Formulating the approach	Chapter 1 (Introduction)
3. Analysing the problem	Chapter 2 (Literature Review) and Chapter 3 (Current Situation)

4. Formulating (alternative) solutions	Chapter 4 (Formulating a Solution)
5. Choosing a solution	Chapter 4 (Formulating a Solution)
6. Implementing the solution	Chapter 5 (Implementing Solution and Evaluation)
7. Evaluating the solution	Chapter 5 (Implementing Solution and Evaluation) and Chapter 6 (Recommendations and Conclusions)

Table 1.1 - MPSM Activities

1.5 Research Questions

The main research question is concerned with creating a storage assignment policy that helps EvW decrease the distance traveled when picking orders. Thus, the main research question can be formulated as:

"How can a storage assignment policy improve the order-picking efficiency in EvW's warehouse?"

To answer this main research question, there are sub-research questions that first need to be answered. In addition, Table 1.2 shows which sub-research questions relate to which chapters of this report. The sub-research questions are shown below:

1. Which theories exist about storage assignment policies?
    a. What are the different types?
    b. Which policies decrease travel distance in order picking?

2. Which theories exist about routing policies?

3. Which existing methods and theories can be used to store slow and fast movers in a warehouse efficiently?
    a. How to identify fast and slow-moving inventory?
    b. Where should each type be stored in the warehouse?
    c. How many storage locations should be given to each type?

4. What is the current situation in the warehouse?
    a. What is the current layout of the warehouse?
    b. What is the current storage assignment policy?
    c. How is order picking currently organized?
    d. What are frequently ordered products?
    e. Which products are frequently ordered together?
    f. What is the routing policy used?

5. How can the findings be applied to EvW's warehouse?
    a. Which storage assignment policy is chosen and why?

Sub-Research Question	Chapter
1. Which theories exist about storage assignment policies?	Chapter 2 (Literature Review)
2. Which theories exist about routing policies?	Chapter 2 (Literature Review)
3. Which existing methods and theories can be used to store slow and fast movers in a warehouse efficiently?	Chapter 2 (Literature Review)
4. What is the current situation in the warehouse?	Chapter 3 (Current Situation)
5. How can the findings be applied to EvW's warehouse?	Chapter 4 (Formulating a Solution)

Table 1.2 - Report Structure

1.6 Research Design

Now that the research questions have been defined, a general plan must be thought of in terms of how these questions will be answered. Table 1.3 represents this plan for each sub-question.

Research Question	Research Type	Research Subjects	Data Gathering Method	Data Analysis Method
1. Which theories exist about storage assignment policies?	Exploratory research	Researchers	**Literature study:** To study existing storage assignment policies that make order-picking quicker.	**Qualitative** Cross-case Analysis: Different research papers are compared and different storage assignment policies are evaluated.
2. Which theories exist about routing policies?	Exploratory research	Researchers	**Literature study:** To study existing routing policies that can be used.	**Qualitative** Cross-case Analysis: Different research papers are compared and different storage assignment policies are evaluated.
3. Which existing methods and theories can be used to store slow and fast movers in a warehouse efficiently?	Exploratory research	Researchers	**Literature study:** To see how other warehouses store fast and slow movers.	**Qualitative** Cross-case Analysis: Different storage methods for fast and slow-moving inventory are compared and analyzed.

4. What is the current situation in the warehouse?	Descriptive research	EvW warehouse workers and management	**Interviews**: to gain more knowledge from the workers. **Observation**: To observe the knowledge gained.	**Qualitative** Conceptual Mapping: Similar concepts are grouped. **Quantitative** Cluster Analysis: So that similar data, such as inventory type, are grouped for easier analysis.
5. How can the findings be applied to EvW's warehouse?	Explanatory research	EvW Warehouse Management and Researchers	**Interviews:** To learn about any layout restrictions and preferences. **Literature study:** To learn about relevant implementation methods.	**Qualitative** Conceptual Mapping: So that layout restrictions and preferences are mapped together with layouts that meet those requirements.

Table 1.3 - Research Design

2. Theoretical Framework

This section investigates existing storage assignment policies in literature and theories that can be used to store slow and fast movers in a warehouse efficiently. The aim is to find research on ways to improve order picking. To come to this, research is first done on basic elements such as warehousing principles in section 2.1, and section 2.2 explains what order picking is, and its importance in warehousing. In addition, the main points of focus are in sections 2.3 and 2.4 as they discuss storage assignment policies, fast and slow movers, and routing policies. Finally, section 2.5 provides a description of which methods are used in this thesis.

2.1 Warehousing Principles

A warehouse, as described by Richards (2014), is a place to temporarily store inventory, and as a buffer to supply chains. It aims to match product availability to customer needs and to assist in the transportation of goods from the supplier to the customer in a cost-effective and timely manner (Richards, 2014). Thus, warehouses are crucial for supply chain success as they ensure the right products are picked, in the right quantities, in the right conditions, and are labeled and loaded for transportation, at the correct times, in the correct vehicles, such that customer demand can be satisfied (Richards, 2014). Furthermore, Bartholdi and Hackman (2002), mention other advantages of a warehouse such as:

1. Consolidating products: transportation costs are reduced by gathering several small orders and making use of a full truckload to transport once to several customers, rather than having a less-than-truckload (LTL) be used multiple times to fulfill customer orders. Thus, warehouses can be used as a place to gather several small orders to load a full truckload for cheaper transportation.
2. Realizing economies of scale: a warehouse can receive a price break when buying in bulk from a supplier such that the amount saved on the purchase can compensate for the costs of storing the product.
3. Providing value-adding processes: for example, warehouses can be used for light assembling, such that parts or components are assembled to form one generic part, such as a keyboard or a hard disk. Manufacturers can use this postponement method to meet demand, increase product differentiation, result in more accurate demand forecasting, and lower safety stock.
4. Reduce response time: warehouses are advantageous when it comes to decreasing lead time. For example, if a product is shipped from Europe to Asia, there is a high chance that through each stage of the transportation, there can be a delay due to congestion, weather, or road conditions. Thus, lead time is increased. However, if the products are already stored in a warehouse in Asia, then the lead time would be shorter and more reliable since the transportation is within Asia.

In addition, a warehouse has several common activities. These are: receiving, put-away, order picking, sortation, cross-docking, and shipping (De Koster et al., 2006). The first two activities, receiving and put-away, are also known as the inbound activities, where products are transferred into the warehouse (Bartholdi and Hackman, 2002). Receiving is the arrival of goods to a warehouse. The products usually come in large quantities, such as pallets, and they are unloaded and scanned to register their arrival and update the inventory record (Bartholdi and Hackman, 2002). Lastly, the products are then inspected to make sure they are in the right quantity, condition, and descriptions.

Put-away is when incoming products are transferred to their storage locations (De Koster et al., 2006). In addition, the storage location should be scanned to know where the product has been placed (Bartholdi and Hackman, 2002). The four remaining activities, order-picking, sortation, cross-docking, and shipping, are also known as outbound activities, meaning activities where the product is transferred out of the warehouse (Bartholdi and Hackman, 2002). Order picking is the major activity in a warehouse and it involves picking the right amounts of the right products for a set of customer orders (De Koster et al., 2006). This activity accounts for 55% of all warehouse operation costs and can be broken down into traveling, searching, extracting paperwork, and other activities (Bartholdi and Hackman, 2002). The next activity is the sortation, and this is where the picked products are sorted into individual customer orders (De Koster et al., 2006). Cross-docking refers to inbound goods being directly transported to shipping docks, skipping the put-away phase (De Koster et al., 2006). Finally, shipping is when products are shipped to the customers.

2.2 Order-picking

Order-picking is considered the highest priority area for improvement, as it is the most labor and capital-intensive operation in warehousing (De Koster et al., 2006). Order picking is the process of gathering and scheduling customer orders, retrieving products from their storage locations, putting them into order lines, and getting them ready for shipment (De Koster et al., 2006). Order lines are groups of different stock-keeping units placed on the floor near the depot, representing different customer orders. They are then loaded into the trucks for shipping. A key statistic in order picking is the flow time, which measures the time starting from the arrival of an order into the system until it has been loaded onto a truck for shipping (Bartholdi and Hackman, 2002). In addition, order picking is widely broken down into sub-processes: travel, search, pick, set-up, and other, as shown in Figure 2.1. Travel comprises the greatest time and is seen as a 'waste' since it costs labor hours but does not add any value (Bartholdi and Hackman, 2002). In addition, two types of travel distances are identified: the average travel distance of a picking tour and the total travel distance. Thus, minimizing the travel distance is a key step to reducing overall picking times (De Koster et al., 2006).

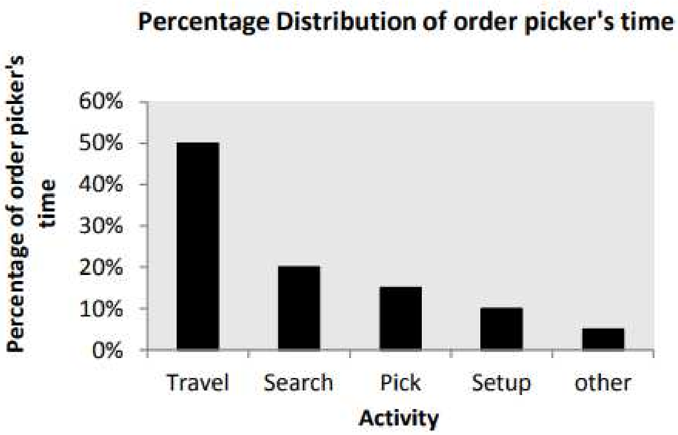


Figure 2.1 - Distribution of order picker's time (Tsige, 2013).

Many order-picking systems are used in warehouses and they usually differ if humans or automation is used. If humans are employed, which is generally the case, order picking is distributed into three systems: picker-to-parts, put system, and parts-to-picker (De Koster et al., 2006). The picker-to-parts system is when an order picker walks or drives to retrieve a product (De Koster et al., 2006). This system has two types, namely the low-level picking and the high-level picking. A low-level picking system is when a worker picks a product from a storage rack. In contrast, high-level picking is when a worker picks a product using a forklift or crane due to high storage racks being employed (De Koster et al., 2006). On the other hand, the parts-to-picker system is an automated storage and retrieval method that uses aisle-bound cranes to pick one or more pallets and bring them to a pick position such as a depot (De Koster et al., 2006). This method, also known as the storage and retrieval S/R machine can be used for single, dual, and multiple command cycles. Finally, a put system consists of two phases: the first is that products are retrieved from storage locations using a picker-to-parts system or a parts-to-picker system. Then an order picker distributes these pre-picked items over customer orders (De Koster et al., 2006). In terms of the order-picking types, EvW uses a normal picker-to-parts system.

There are many objectives for order-picking. These are (De Koster et al., 2006):

- Minimize picking time.
- Minimize the throughput time of an order.
- Maximize the use of space.
- Maximize equipment utilization.
- Maximize labor utilization.
- Maximize accessibility to all products.

In addition, there exist many order-picking types, such as zoning, single order-picking, and batching. Single-order picking, or discrete picking, is when one customer order is fulfilled at a time (Reynolds, 2024). This usually happens because the orders are large. Zoning is an alternative to single order-picking and it is when the picking area is separated into different zones (De Koster et al., 2006). The order pickers are then assigned to these zones and must pick the SKUs only in their zones. This helps with congestion and makes each order-picker travel small distances. However, the disadvantage is that orders are split and must be consolidated in the end, causing difficulties (De Koster et al., 2006). Lastly, batching is when several small orders are picked at the same time, at once, instead of using the single order-picking method to pick orders one at a time (De Koster et al., 2006). This becomes fairly easy to implement since the orders are small. Moreover, by batching orders, the traveling distance can be decreased since a single tour is used to pick the orders. In addition, Schuur (2015) states that order picking usually occurs in two scenarios: single and multi command. Single command order picking is when the order picker starts at the inbound/outbound (I/O) doors, picks only one item/product from the storage location, and returns to the I/O doors in one tour (Schuur, 2015). On the other hand, multi command order picking is when more than one product is picked in one tour (Schuur, 2015).

Furthermore, a popular strategy to reduce the workload of order-picking is to divide the warehouse into a forward area and a reserve area (Van Den Berg et al., 1998). The forward area is used for efficient order-picking, while the reserve area is used to hold bulk storage for replenishing the forward area when it is depleted and to store products that are not stored in the forward area (Van Den Berg et al., 1998). Moreover, warehouses usually store the reserve and forward products in the same pallet rack, with the forward area being low, in a range where the order-picker can easily pick items with his hand, and the reserve is higher up in the rack. Some warehouses even divide the reserve area into two separate sections: order-picking and replenishing (Van Den Berg et al., 1998). In addition, the products that are stored in the forward area are usually limited either because increasing the forward area would result in large distances to be traveled, or large orders would become too expensive (Van Den Berg et al., 1998). Van Den Berg et al. (1998) take on the forward-reserve problem to decide which products belong to the forward and the reserve areas, and in which amounts. They also distinguish between replenishments during busy and idle periods, where busy periods are picking periods and the idle period is the time before the pick periods. An assumption is made that replenishing during the idle periods reduces the workload during the picking period which increases the throughput of the operation, and reduces congestion and accidents (Van Den Berg et al., 1998). The authors model the problem as a binary programming problem and present the GKH which finds solutions close to the optimum regarding the number of unit loads to be stored. In addition, they conclude that major labor-time savings can be achieved by intelligently allocating products in the forward area and by permitting order-picking in the reserve area, which would however require some additional investments for special equipment (Van Den Berg et al., 1998).

2.3 Storage Assignment Policies

For products to be picked, they must first be placed in storage locations. A storage assignment method is a set of procedures that can be used to allocate products in storage locations (De Koster et al., 2006). A storage assignment policy is a rule that indicates how and where to assign products in the warehouse. Storage assignment is essential to reducing travel distances and order-picking time (Tambunan et al., 2018). The 5 most common policies are random storage, closest open location storage, dedicated storage, full turnover storage, and class-based storage (De Koster et al., 2006). Table 2.2 gives a summary of these policies.

Storage Assignment Policy	Definition	Advantages/Disadvantages
Random Storage	Random storage is when a product is stored randomly from all eligible empty spaces with equal probability.	Advantages: ● High space utilization. Disadvantages: ● Increased travel distance. ● Only works in a computer-controlled environment.
Closest Open Location Storage	The first empty location that meets the worker is used to store the product.	Advantages: ● Decreased travel distance. ● Increased worker autonomy Disadvantages: ● Sometimes might lead to a design where the racks are full near the entrance and are

		gradually emptier around the back.
Dedicated Storage	Each product is stored at a fixed location.	Advantages: ● Order pickers become familiar with product locations. ● Can create a good stacking sequence by placing heavy products on the bottom, and light products on the top. Disadvantages: ● Low space utilization since a space is reserved for a product even if it is not currently available. ● For every product, space is reserved such that the maximum level of inventory can be stored. This also causes low space utilization.
Full-turnover Storage	This policy, which is a type of dedicated storage, locates products based on their turnover. The products with the highest sales rates or the most frequently ordered are located for easy and fast picking, somewhere near the dock doors, whereas low-sales products are stored further away from the dock doors. A storage type of this policy is the cube-per-order-index (COI) rule, which is a ratio of a product's total required space to the number of trips required to satisfy its demand per period. The products with the lowest COI are placed near the dock doors.	Advantages: ● Fast and efficient order picking. ● Low-distance travel. Disadvantages: ● Demand rates are constantly changing, meaning the product assignment would constantly need to change as well. This would require constant changing of the storage locations, causing a large amount of reshuffling stock. ● This method requires data on product location, demand, and sales. If this data is not attainable then the assignment policy

		cannot be done.
Class-based Storage	This method divides products into classes based on some measure of demand frequency such as COI or pick-volume. Products are categorized into classes so that the fastest-moving class contains about 15% of the products stored but represents 85% of the turnover. The fastest-moving items are identified as class A, the medium-moving are class B, and the slowest are class C, and each class is assigned to a dedicated area, and storage within each area is random. Figure 2.2 shows an example of how the classes would be stored in a warehouse.	Advantages: ● Fast-moving products can be stored near the depot, resulting in low travel distances and quicker picking times. Disadvantages: ● To store an incoming product, a slot must be available in a specific class region, thus increasing storage space requirements and decreasing space utilization. ● More rack space is required than randomized storage.

Table 2.2 - Storage Assignment Policies (De Koster et al., 2006).

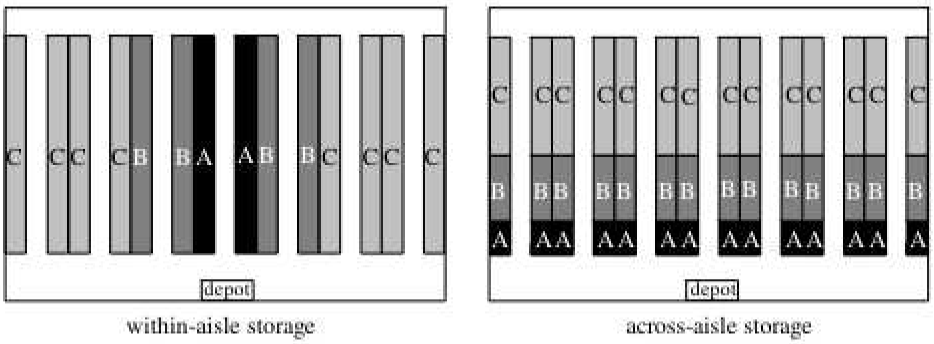


Figure 2.2 - Class-based Storage policy (De Koster et al., 2006).

Furthermore, some authors only distinguish between 3 common storage policies: Dedicated, Shared, and Class-based policy. This is because many scholars describe a class-based storage policy as a mix of a dedicated and shared policy. The idea is that products are divided into classes, in a class-based policy, and are given fixed storage areas in the warehouse, per class (dedicated policy), but storage within each of the fixed areas, for each class, is random (shared policy) (L. Cardona, 2019).

In addition, many papers were studied to identify what previous researchers have done with storage assignment policies for better order-picking. Tarczyński (2017) investigated the cube-per-order-index (COI) policy to identify the conditions where it performs better than only using picking-frequency or a random storage policy in a picker-to-parts warehouse system. The author states that a COI storage system heavily relies on four criteria: popularity, space, compatibility, and complementarity. The first two refer to the general definition of COI (ratio of space needed by a product to its order frequency). Compatibility means that products that do not match, should not be stored together, such as food and gasoline. Finally, complementarity means that items that are frequently ordered together, are stored close together. Tarczyński (2017) comes to the results that using a class-based storage policy by assigning items using a COI method or only by order frequency significantly outperforms a random storage policy as it can result in twice shorter travel distances. In addition, when many items are picked in one tour the storage based on picking frequency is better than the storage based on the COI.

Moreover, Mantel et al. (2007) show that a slotting strategy, without batching, can outperform a COI slotting strategy in single-order picking. They minimize the total traveling time of all tours by using the Order Oriented Slotting (OOS) strategy which assigns SKUs that are ordered frequently together close to each other. Along with many other heuristics, Mantel et al. (2007) mainly use the interaction frequency heuristic to identify and allocate SKUs that are frequently ordered together.

Furthermore, Schuur (2015) investigates the COI policy on single and multi command order picking levels. He states that for single command order picking, the COI storage policy is well known to decrease order picking travel time, but not so much for multi command order picking since an order oriented slotting (OOS) proves to be more optimal (Schuur, 2015). In a test where the COI was compared to the OOS storage policy, it turned out that the COI policy decreased the total distance traveled by 27%, while the OOS decreased it by 40%. Thus, Schuur (2015) examines how bad the COI policy can be, and shows that there is no limit to this badness.

In addition, Guo et al. (2016) studied the difference in travel performance of a class-based, random, and full turnover-based storage policy given the required storage space. Firstly, the average travel distance of a random policy is found to not be constant but decreases with the increase in the skewness of the ABC demand curve as the warehouse becomes smaller. In addition, by using a full-turnover policy to rank items based on their turnover, the average travel distances decrease by increasing the system efficiency. However, the full turnover policy needs 50% more storage space than a random policy as items cannot share the same space in the same class. The authors conclude that balancing the tradeoff, a class-based policy with minimal classes is optimal.

Furthermore, Zhang et al. (2019) take a similar approach and introduce the concept of demand correlation pattern (DCP) to store items that are usually collectively ordered together in the same storage areas. The storage assignment problem is formulated as an integer linear programming model, and two heuristics are used: minimum increment heuristic (MIH) and simulated annealing (SA). The results indicated that the MIH is useful when items are weakly correlated and order size varies. In addition, the SA yields very competitive solutions when items are highly correlated. Finally, it is more effective to apply a correlation-based storage strategy in warehouses with more storage locations per aisle. Another similar terminology found was family grouping. This is when products that are ordered frequently together are stored together for easier picking (De Koster et al., 2006).

2.4 Routing Policies

Another factor that affects order-picking efficiency, along with storage assignment policies, is routing policies. Routing policies are ways to sequence pick items in an order such that a good route that minimizes distance traveled for example is made (De Koster et al., 2006).

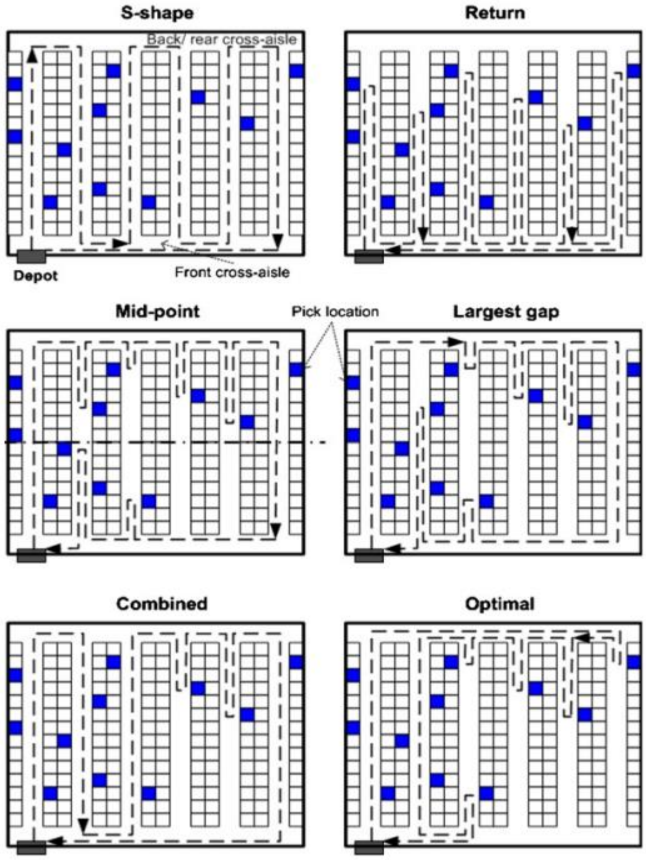


Figure 2.3 - Routing Policies (De Koster et al., 2006).

Figure 2.3 shows the most common routing policies used in the literature. Starting with S-shape, any aisle containing at least one pick is traveled completely until the end, however, aisles with no picks are not traveled (De Koster et al., 2006). The return method is when a picker enters and leaves an aisle from the same end (De Koster et al., 2006). By splitting the warehouse into two parts, the midpoint method treats each part separately when picking and follows a similar behavior as the return policy for both sides (front and the back). The back side is reached by either visiting the first or the last aisle when picking (De Koster et al., 2006). Similar to the midpoint method, the largest gap policy is when an order picker enters an aisle as far as the largest gap within an aisle, instead of the midpoint (De Koster et al., 2006). The gap is represented as the distance between two adjacent picks. The combined policy is when an aisle is completely traveled or is entered and returned from the same side (De Koster et al., 2006). This choice is generally made using dynamic programming.

2.5 Approach Chosen

The approach chosen is a dedicated storage policy to reorganize zones A, F, G, H, and I of the warehouse for lower travel distances when picking orders, instead of the random storage policy that is currently being used. More specifically, the COI storage policy is chosen because the warehouse has not considered the pick frequency of products, and this can already increase order picking efficiency. Furthermore, this storage policy works best for decreasing the travel distance in single command order picking (Schuur, 2015). For multi command order picking, the OOS storage policy is used to store products that are frequently ordered together, close to each other. This is also something the warehouse has not done yet, and this works best to decrease the travel distance in multi command order picking (Schuur, 2015). Finally, the return routing policy is chosen when calculating the travel distance and comparing the new and old layouts.

Two things are needed to create and implement the COI storage policy: the product's required storage space and the number of times it has been picked in different orders. These two factors help create an improved storage layout by calculating the COI ratio and using it to rank the products in the zones. The ratio works by storing the products with the highest pick rates and the lowest storage requirements closest to the dock doors. Once the COI policy is implemented in the zones, the OOS policy is used to improve the storage location assignment further. This is done by locating products that are frequently ordered together, closer to each other if they are not already. The OOS is only added if there is multi command order picking in a zone. By doing this, a combination of both policies is used.

However, the OOS policy is implemented in a simpler process than the methods used by Mantel et al. (2007) since the interaction frequency and the interaction frequency-based quadratic assignment heuristics are not used. Instead of using these heuristics, the products are analyzed and counted to see which items have been ordered with others the most. Similar to the aforementioned papers, by storing these items together, fewer distances are traveled and better order-picking is achieved. More information on how the policies are implemented

To summarize, Chapter 2 tackles the research question by researching basic warehouse principles such as the functions of a warehouse and the order-picking process. Then, research is done on storage assignment policies to find the policies that decrease the travel distances the most when picking orders. The two prominent policies identified are the COI storage policy for single command order picking and the OOS storage policy for multi command order picking. Moreover, the routing policy chosen is the return routing policy. Finally, common strategies that reduce the workload of order picking were studied such as the forward-reserve storage strategy which divides a rack into a pick and bulk area. The next chapter discusses the current situation of the warehouse.

3. Current Situation

In this chapter, a summary of the current situation of the warehouse is given. Section 3.1 presents a description of EvW's warehouse and section 3.2 provides information on the warehouse's capacity. In addition, section 3.3 describes the pallet racks, while sections 3.4 and 3.5 discuss the pallet places and the current storage locations, respectively. Moreover, section 3.6 describes the stock that is currently stored in the warehouse and section 3.7 provides information on the current order picking process. Furthermore, section 3.8 analyzes company data to provide the required information needed to create the COI storage policy. Finally, section 3.9 does the same but for the OOS storage policy. In the end, a chapter summary is given.

3.1 Warehouse

EvW's warehouse is located in the XL Business Park Twente in Almelo, a strategic location, between the A35 and the Twente Canal, making it very easy to transport by road or by inland shipping (Hamed, 2023). The warehouse's main purpose is to store its clients' inventory and take care of their logistics. This can also be referred to as a third-party logistics (3PL) company, which is a fulfillment and logistics partner that helps store and transport inventory (Rheude, 2024). In addition to normal storage, the warehouse allows transshipment or cross-docking to its clients (*Warehouse Almelo - Warehousing E. Van Wijk Forwarding*, 2024).

3.2 Capacity

The warehouse has a storage space capacity of 7,500 m2, 9,000 pallet places, and offers 8 loading docks, 4 in the front of the warehouse for receiving (inbound) and 4 at the other end for the outbound processes.

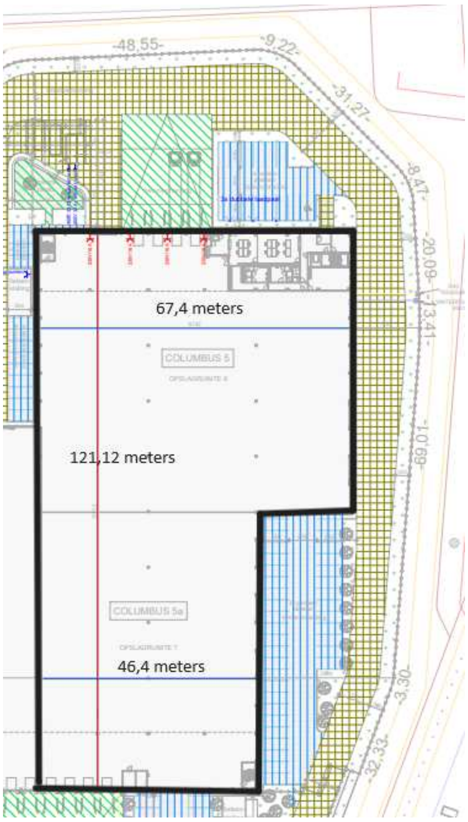


Figure 3.1 - Warehouse Dimensions (Bird-eye view).

Figure 3.1 shows a sketch of the building, with its dimensions, including the warehouse. As can be seen, the warehouse is split into two parts, the first part is labeled as Columbus 5, and the second part is Columbus 5A. In reality, the warehouse is one complete space, however, this division is more theoretical to divide the inbound and outbound areas of the warehouse and to show the difference in dimensions. From the figure, it can be seen that the warehouse has a total length of 121.12 meters, which is highlighted in red. In addition, the first part of the warehouse has a width of 67.4 meters and the second part has a width of 46.4 meters which are both highlighted in blue. Also, Figure 3.2 shows a front-side view of the building, and the warehouse has a total height of 14.1 meters.

Figure 3.2 - Warehouse front view

3.3 Pallet Racks

Figure 3.3 - Pallet Racks

EvW has a total of 292 single-deep pallet racks in the warehouse, each being 11 meters tall. The whole height of the warehouse (14.1 m) cannot be used due to the sprinkler system implemented in the ceiling. In addition, each (storage) level in a rack can take 4 Euro pallet places but only 3 Blok/American pallets, and has a loading capacity of 4450 kg. Furthermore, there are 6 levels in a rack, going from the floor location to the highest level. Thus, each rack has 24 pallet places (6x4).

3.4 Pallet Places

As previously discussed, the warehouse is very big as it offers around 9,000 pallet places of storage. Unfortunately, only 1,506 pallets are currently occupied because a major client, that took a huge part of the warehouse, left before the beginning of this assignment. As can be seen in Figure 3.4 the graph shows how the occupation of pallet places changes throughout the months. A sharp decrease between March and April is evident, which is when the client departed.

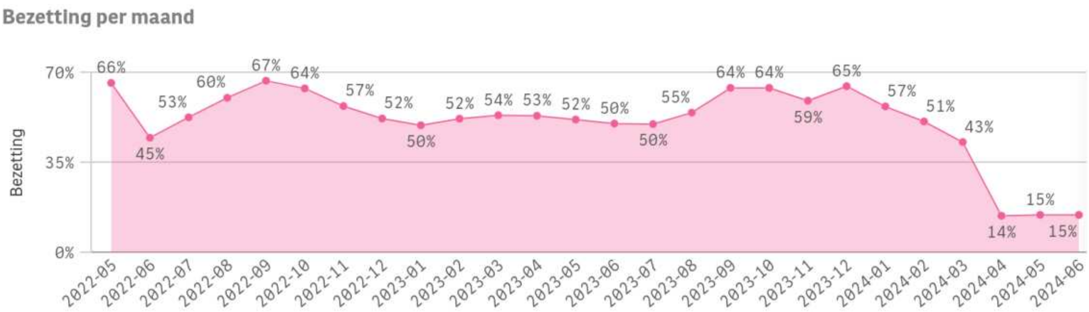


Figure 3.4 - Pallet place occupation per month.

3.5 Storage Locations

The current 1,506 occupied pallet places are spread out and scattered all over the warehouse. In addition, the racks are divided into zones, which are labeled as A, B, C,..., U, and Z. Depending on the zone, there exists between 10-20 racks in each zone. For example, zone A has 17 racks, zone F has 20, and zone J has 10. The warehouse workers generally divide their clients' inventories into these zones such that one client is stored in one zone and another client is in a different zone.

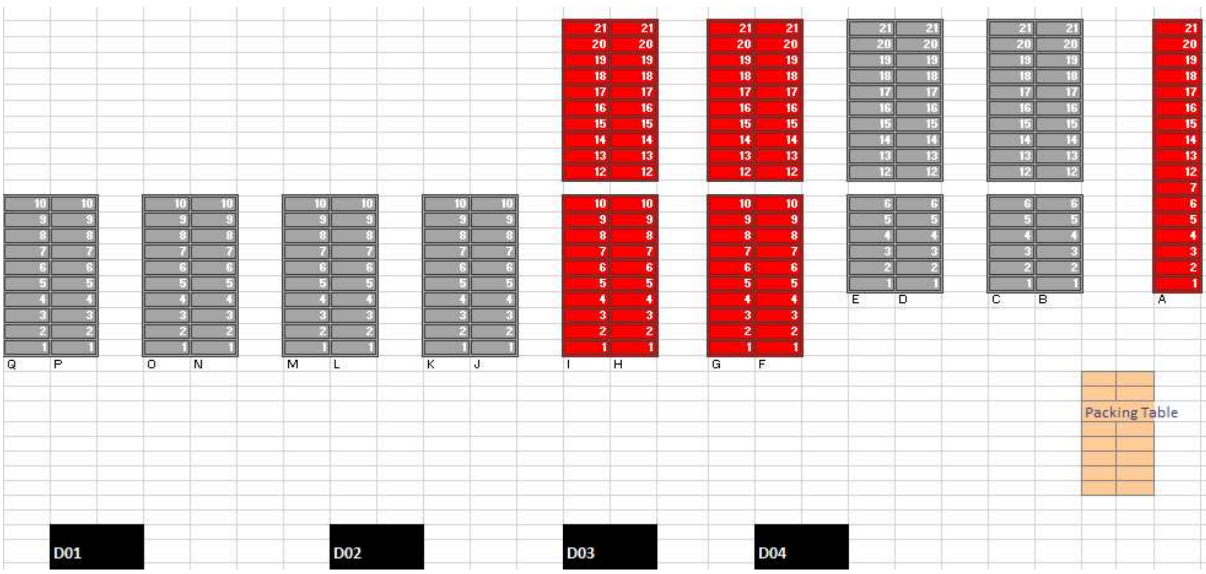


Figure 3.5 - Warehouse Sketch

Figure 3.5 shows a sketch of the warehouse created in Excel. Due to the size of the warehouse, Figure 3.5 only shows a snapshot of the sketch, and not the whole picture. Figure A.1 in Appendix A shows the complete picture with more zones. Zones A, F, G, H, and I are highlighted in red as these are the areas of focus. In this figure, each grey cell indicates a pallet rack. In addition, the dock doors are shaded in black at the bottom and the packing table is shown on the right in yellow, below zones A and B. The packing table is where e-commerce products go so they can be packed into boxes before being sent to the dock doors.

Most e-commerce products are stored in zone A, which is a strategic location since they are close to the packing table. These products are stored randomly. In addition, the zone is not divided between forward and reserve for faster order picking. Moreover, zone A has 17 pallet racks numbered from 1 to 21. After the 7th rack, a transition is made to the 12th rack to indicate a change to the backside of the warehouse. In the warehouse, starting from the 12th rack indicates the back side of the warehouse, while all the racks before the 12th indicate the front side of the warehouse, which is close to the outbound dock doors.

Previously, the big client used to be stored in the front racks of zones F, G, H, and I which are the racks going from 1 to 10 in red, in Figure 3.5. After its departure, these racks have been left unoccupied and no products are stored there. In addition, there are many products stored in these same zones, but in the back, going from racks 12 to 21, which are also highlighted in red. Now that the big client has left, the products in the back can take the unused storage locations of the racks in the front to decrease the distance traveled to the dock doors.

Figure 3.6 - Storage Locations

Before advancing to the next section, it is important to describe the storage locations in the racks. The storage locations are printed as yellow stickers on all the racks, which can be seen in Figure 3.6. These stickers have six characters (numbers and letters) to describe a specific location in the warehouse. The first letter in the storage location is always the zone. If a product is in zone A, the first letter would be “A”. Next, two numbers are written to indicate which rack the product is stored in. For example, the first rack would be written as “01”. After this, one letter is written to show which slot, out of the four, the product is stored in. As previously described, each level in a rack can store four euro pallets. These four options are given by “A”, “B”, “C”, or “D”, where “A” is the first slot on the right, and “D” is the last slot on the left. Finally, two numbers are written at the end to indicate which height level a product is stored in. The lowest level is the floor location and is written as “00”. In addition, the levels above it are “10”, “20”, “30”, etc. If we take the pallet on the bottom right as an example, which is shown in Figure 3.6, its storage location is “A01A00” indicating that it is stored in zone A, in the first rack, in slot A, and on the floor.

3.6 Stock

3.6.1 Zone A

Zone A is home to most e-commerce products in the warehouse. The warehouse manager prioritizes these products because they need to be delivered fast and on time to the customer without any delays. However, other products in the warehouse are more flexible to time and delivery requirements.

E-commerce Clients/Companies	Zone
Jeanette Kershof	A
Mennegat	A, Z
Noordliving	B
Mercis	A
Mr. GPS	A
PIMZOS	A
Bowiq	A

Table 3.1 - E-commerce clients

Table 3.1 shows a list of all the e-commerce clients/companies in the warehouse and their corresponding locations. As can be seen, most of them are stored in zone A. Jeanette Kershof is a woman who started an online webshop that sells medicine and products, such as gels and creams, that help with a skin disorder known as Vitiligo. In total, she has 84 different products stored in the warehouse, and she is a prominent client with many orders. In addition, Mennegat is the number one distributor of professional audio equipment in the Netherlands, making it also a critical e-commerce client and it has a total of 1650 products in the warehouse. (*Over Mennegat Trading BV - #NR1 Pro Audio Distributeur in Nederland*, n.d.). Furthermore, the table shows that some of Mennegat's inventory is stored in zone Z, which is the zone furthest away from the packing table. This means large distances are traveled when picking orders. Noordliving, on the other hand, is the only e-commerce client that is not stored in zone A since it occupies all of zone B by itself. This is because it is the e-commerce client with the largest amounts of products stored in the warehouse. Looking at the rest of the client list, Mercis, Mr. GPS, PIMZOS, and Bowiq are all stored in zone A.

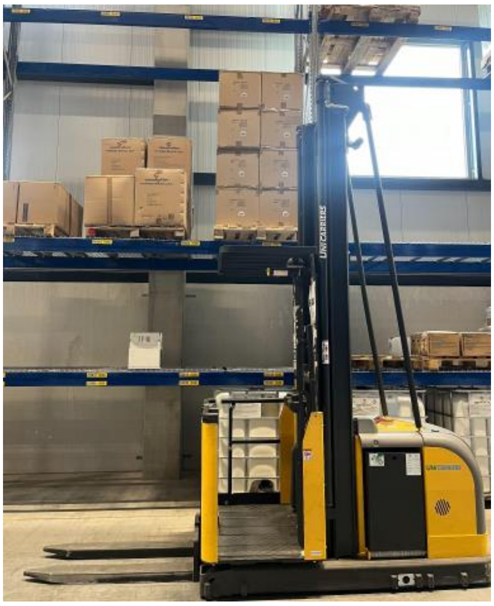


Figure 3.7 - Mennegat Zone Z

When the warehouse workers were asked why some of Mennegat's products were stored in zone Z, the answer was that they were stored there because some pallet loads were too tall to fit in the locations of zone A. Figure 3.7 shows some of Mennegat's pallet loads in zone Z. The pallet load on the right is how a palled load initially starts. The other pallet loads on the left only show what remains of them after a certain period of order picking. These pallet loads, however, started with the same height as the palled load on the right.

The pallet loads are very high because Mennegat stores as many products as possible, using the least amount of pallets, to avoid being charged money for occupying a lot of locations. Thus, Mennegat sends in pallet loads that are about two meters tall, especially for their most ordered products. In addition, as can be seen in the figure, the pallets are stored in high locations, meaning a forklift must be used so that the order picker can elevate himself to the height of the tallest box, cut it open with a knife, and pick as many products/items demanded by the customer. This process takes a lot of time and increases the travel distance.

When this situation was discussed with the Warehouse Manager and the Managing Director, the Managing Director was unaware of the situation and stated that there is a rule restricting pallet loads from exceeding 160 cm in the warehouse. Moreover, all loads exceeding 160 cm should be split up into two pallets instead of one. Thus, for every pallet that is stored in zone Z exceeding 160 cm, it will be divided into two pallets instead of one. The current heights of the pallet loads in zone Z are 200 cm, therefore these will be divided into two 100 cm pallets. By doing so, the 100 cm pallet loads can be located in zone A. Table B.1 in Appendix B shows the products stored in zone Z and how many locations they occupy.

3.6.2 Zones F-I

This thesis also focuses on different products, such as the ones belonging to zones F, G, H, and I in the back. These products belong to a client called Pentair. Pentair is a water treatment company that is focused on smart, sustainable water solutions (Null, 2024). Pentair Water Solutions provides ways to improve their customers' trust in water while reducing the environmental impact (Null, 2024). Moreover, Pentair Flow optimizes the flow of essential resources to improve communities and industries (Null, 2024).

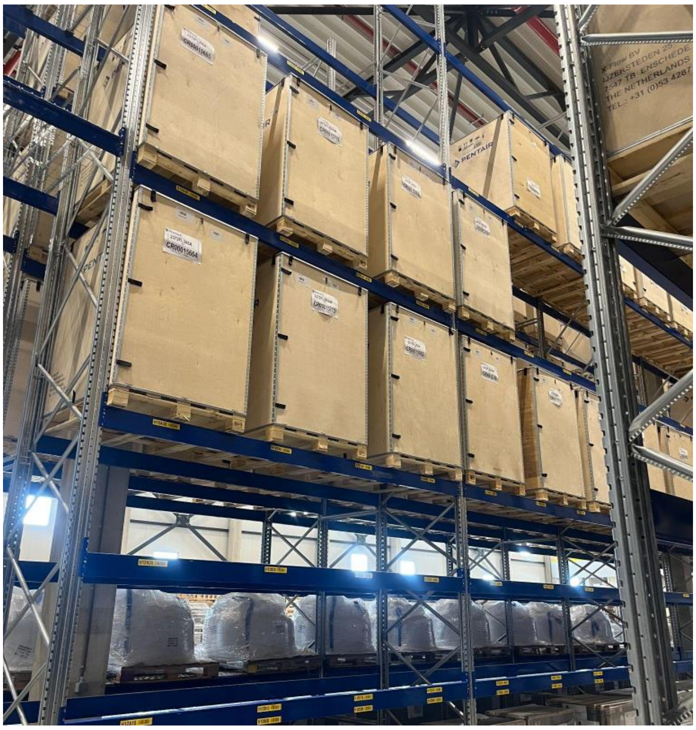
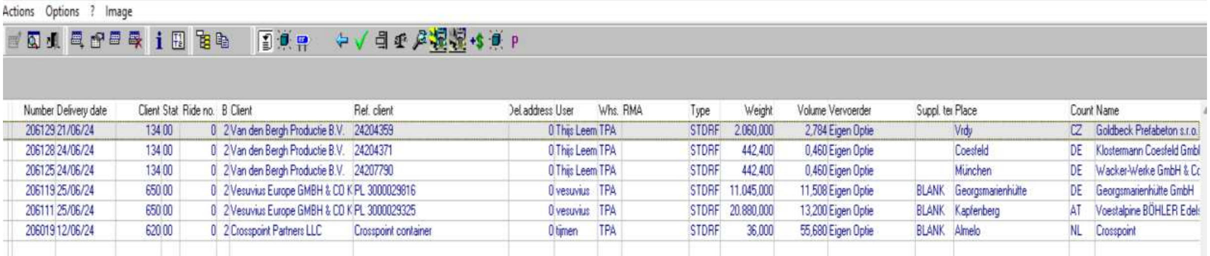


Figure 3.8 - Pentair X-Flow

Pentair's stock consists of different water filtration and treatment machines that are stored in large boxes in the warehouse. These boxes are stored on pallets in the racks. A picture of Pentair's products stored in zone H is shown in Figure 3.8. It can be seen that they all look similar to one another since they have the same appearance, but they are actually different. In addition, it can be seen that most of them are stored in high places in the racks due to their tall height and low weight. They are mostly stored on the level 30 and above. Also, due to the pallets' big sizes, they take up only three pallet places per level: A, B, and D instead of four (A, B, C, D).

3.7 Order-picking

EvW's order-picking now is calmer than before. After the departure of their big client, the number of orders dropped and so did the number of order pickers. There are only 3 order pickers: two working full-time and one part-time. There are on average 25 orders per day now, but when the big client was here, there used to be around 200 orders per day. There were also more order-pickers then. In general, an order amount varies in a day. For example, one order could be very big, while another order could be very small. In addition, the number of orders in a day is not known in advance. Thus, orders are treated separately and they are completed one at a time. In other words, different orders are not batched or consolidated. The order picking process starts when EvW is notified of a new order through their warehouse management system (WMS). In the warehouse department, there is a person responsible for frequently checking the WMS to see if a new order arrived. This order usually contains important information such as the delivery date, which client the order is for, and which products are needed.

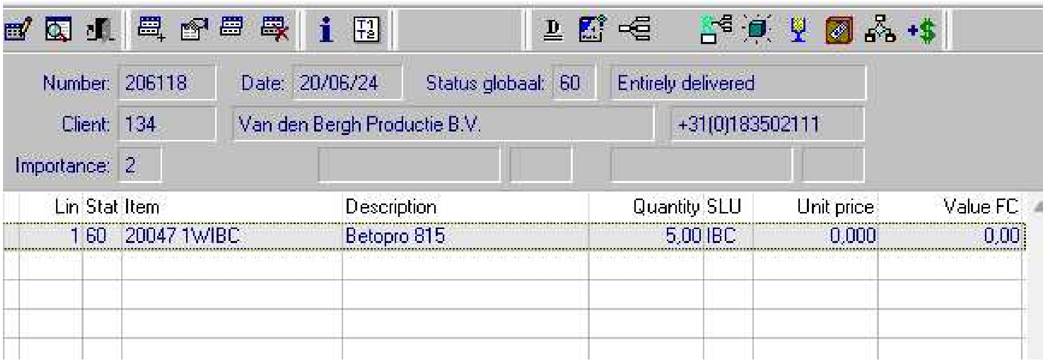


Actions Options ? Image

Number	Delivery date	Client	Stat	Ride no.	B	Client	Ref. client	Del.address	User	Whs.	RMA	Type	Weight	Volume	Vervoerder	Suppl. ter	Place	Count	Name
206129	21/06/24	134	00	0	2	Van den Bergh Productie B.V.	24204359	0	Thijs Leem	TPA		STDRF	2.060,000	2,784	Eigen Optie		Vrdy	CZ	Goldbeck Prefabeton s.r.o.
206128	24/06/24	134	00	0	2	Van den Bergh Productie B.V.	24204371	0	Thijs Leem	TPA		STDRF	442,400	0,460	Eigen Optie		Coesfeld	DE	Klostermann Coesfeld Gmbl
206125	24/06/24	134	00	0	2	Van den Bergh Productie B.V.	24207790	0	Thijs Leem	TPA		STDRF	442,400	0,460	Eigen Optie		München	DE	Wacker-Werke GmbH & Cc
206119	25/06/24	650	00	0	2	Vesuvius Europe GMBH & CO K	PL 3000029816	0	vesuvius	TPA		STDRF	11.045,000	11,508	Eigen Optie	BLANK	Georgsmarienhütte	DE	Georgsmarienhütte GmbH
206111	25/06/24	650	00	0	2	Vesuvius Europe GMBH & CO K	PL 3000029325	0	vesuvius	TPA		STDRF	20.880,000	13,200	Eigen Optie	BLANK	Kapfenberg	AT	Voestalpine BÖHLER Edel
206019	12/06/24	620	00	0	2	Crosspoint Partners LLC	Crosspoint container	0	tijmen	TPA		STDRF	36,000	55,680	Eigen Optie	BLANK	Almelo	NL	Crosspoint

Figure 3.9 - Orders

For example, Figure 3.9 shows a list of different orders in a day. An important thing to note is that each order corresponds to one client. This means that every order is directed to one client, and only one client. As a result, an order cannot ask for a product from one client and another product from a different client. It is only possible to order products belonging to that same client/company. If one of the orders in Figure 3.9 is clicked on, then more details appear.



Number: 206118 Date: 20/06/24 Status globaal: 60 Entirely delivered

Client: 134 Van den Bergh Productie B.V. +31(0)183502111

Importance: 2

Lin	Stat	Item	Description	Quantity	SLU	Unit price	Value FC
1	60	20047 1WIBC	Betopro 815	5,00	IBC	0,000	0,00

Figure 3.10 - Order for 5 Ecoratio pallets

As seen in Figure 3.10, one of the orders wants 5 pallets of the product, “Betopro 815” to be picked, belonging to a client called Ecoratio. Once an order has been received in the WMS, the person responsible for frequently checking the WMS sends the order to the scanner system so that the warehouse workers are notified. This person sits in an office, while the warehouse workers are inside the warehouse.

Figure 3.11 - Scanner

The scanner, shown in Figure 3.11, is essential for daily warehouse operations and is directly connected to the WMS. With this scanner, the workers can see the new orders and know which products need to be picked. In addition, the scanner shows the order picker the storage locations of the products that need to be picked. The locations are saved on the system because the workers also use the scanner when storing products in their storage locations. This is done by first scanning the product barcode, and then scanning the location barcode in the pallet rack so that it is saved in the WMS. As a result, each product has a corresponding storage location in the warehouse. This way, the WMS can track where a certain product is stored and how many of it is in stock. This also helps clients track where their products are and how many of them are still left since they have partial access to EvW's WMS. Thus, when a customer orders a certain product, the order picker knows, through the WMS how many of this product are needed, when it should be delivered, and where to find it in the warehouse. However, the scanner does not tell the order picker the optimal route to take, how to schedule the orders, how many order pickers are required, or how to consolidate order picking between several order pickers. In terms of the routing policy, the order pickers usually follow a return route policy.

Figure 3.12 - Forklift

In addition, the order pickers generally use a forklift to travel to a location when picking pallets, as shown in Figure 3.12. Depending on the size of the order, it is decided whether only one or two order pickers will carry out the job. In the case when an order is small, only one worker will do the picking and that is generally decided based on which of the two is free and has the time to do it. When the order is large, two or three pickers can work together for such an order.

Figure 3.13 - Noordliving

On the other hand, other orders can be hand-picked without using a forklift. These are usually orders for e-commerce clients, who sell low-weight and small-sized products that are stored in boxes on pallets. In such cases, the order picker travels by walking, without using a forklift, and picks the items needed with his hand. Figure 3.13 shows an example of the e-commerce client Noordliving.

Figure 3.14 - Packing Table

When picking e-commerce products, the order picker first picks the needed products with his hand and then must travel to the packing table, shown in Figure 3.14, to pack the products in a box before sending them to the dock doors. After storing the product in a new box, the order-picker prints and sticks a label containing order shipment details like the date, the carrier, the address, and barcodes. This process needs to be done for all e-commerce clients. As a result, these clients must be stored near the packing table to minimize the distance traveled. The ideal locations for these clients are zones A and B which are closest to the packing table.

3.8 COI Storage Policy

In this section, data from the company is analyzed and the required information needed to create the COI storage policy is shown. As discussed in Section 2, the cube per order index is the ratio of a product's storage space requirement to the number of times this product is picked in different orders (Malmborg & Bhaskaran, 1990).

Two things are needed to calculate the COI ratio: the product's required storage space and the number of times it has been picked in different orders. When looking at the number of times each product has been picked, the data is analyzed starting from April (when the big client left the warehouse) since this gives an accurate impression of the current situation. In addition, the data is analyzed until July of that same year.

3.8.1 Zone A

Beginning with zone A, the first step is to see the number of times each product has been picked. Furthermore, because some products in zone Z will be transferred to zone A, these must also be included in the analysis. To do this, the order history from the Warehouse Management System (WMS) is analyzed and Excel functions are used to count the number of times each product has been ordered since April.

Client	Product	Amount of times ordered
PIMZOS.COM	PT100 Outdoor Sensor, Class A, 3-wire	165
Mennegat Trading BV	SONORA-6TN (Black)	156
Mennegat Trading BV	Helvia Internetradio OMNIS-100	128
Mennegat Trading BV	Powersoft MEZZO604A (0610)	65
Mennegat Trading BV	BAS Projector Speaker Industrial	60
PIMZOS.COM	LabJack U3-LV	60
PIMZOS.COM	EX9520R	58
Mennegat Trading BV	Powersoft WM TOUCH 4.3" zwart	58
PIMZOS.COM	Power Cord Schuko 1,8 meter - VDE - Schuko to C13 - Black	56
PIMZOS.COM	PFH16240	55
PIMZOS.COM	IP POWER 9255GE	53
Mennegat Trading BV	Powersoft MEZZO602A (0611)	50
Mennegat Trading BV	Fonestar SONORA-6TB (White)	48
Jeannette Kershof	Vitipro	42
PIMZOS.COM	ACRO DIN-Rail Voeding AD1048-24FS (24VDC/2A)	41
PIMZOS.COM	Apparaatsnoer FWL Schuko Haaks, 1,8 meter, 3 x 0,	41
Mennegat Trading BV	Mag Audio AIR-C8-16-BK-W incl. muurbeugel	36
Jeannette Kershof	DermaBestÂ® Melavitil	31
Mennegat Trading BV	Powersoft MEZZO322A (0613)	27
Mennegat Trading BV	AtlasIED AZM4	23
Mennegat Trading BV	AtlasIED X-ANS-EU	22

Figure 3.16 - Zone A Product Pick Amount

Figure 3.16 shows a picture of an Excel table with all the products in zone A, including the ones that are stored in zone Z, ranked from most ordered to least ordered. Due to the length of the data, Figure 3.16 only shows a snapshot and not the whole picture. The complete table can be found in the Excel file: Zone A. As can be seen from Figure 3.16, the most ordered product is, "PT100 Outdoor Sensor, Class A, 3-wire" stored in zone A, belonging to the client PIMZOS, and has 165 orders. Interestingly, the second most ordered product, "SONORA-6TN (Black)" is one of the products that are currently stored in zone Z, belonging to Mennegat. In addition, the other product in zone Z is, “BAS Projector Speaker Industrial”, which is the fifth most ordered product, also belonging to Mennegat. Because these two products are in the top five most ordered products, this creates a lot of travel distance for the order picker since he must travel to zone Z and use a forklift every time he needs to pick these products.

The second step is to identify the required storage space for these products. This was done in two ways: For the products currently stored in zone A, the methodology was to simply observe the storage locations of each product, on Excel, and count the number of locations each product uses. Because all the products are stored on pallets, the result was the number of pallet places needed for each product. On the other hand, when looking at the products currently in zone Z, the same methodology was used, however, the final number of required pallet places for each product was multiplied by two since the pallet loads needed to be divided into two loads of 100 cm instead of one 200cm loads. As a result, Figure 3.17 adds to the previous table by including the required storage space (pallet places) for each product.

Client	Product	Amount of times ordered	Pallet Places
PIMZOS.COM	PT100 Outdoor Sensor, Class A, 3-wire	165	1
Mennegat Trading BV	SONORA-6TN (Black)	156	2
Mennegat Trading BV	Helvia Internetradio OMNIS-100	128	2
Mennegat Trading BV	Powersoft MEZZO604A (0610)	65	2
Mennegat Trading BV	BAS Projector Speaker Industrial	60	24
PIMZOS.COM	LabJack U3-LV	60	1
PIMZOS.COM	EX9520R	58	1
Mennegat Trading BV	Powersoft WM TOUCH 4.3" zwart	58	1
PIMZOS.COM	Power Cord Schuko 1,8 meter - VDE - Schuko to C13 - Black	56	1
PIMZOS.COM	PFH16240	55	1
PIMZOS.COM	IP POWER 9255GE	53	1
Mennegat Trading BV	Powersoft MEZZO602A (0611)	50	1
Mennegat Trading BV	Fonestar SONORA-6TB (White)	48	1
Jeannette Kershof	Vitipro	42	1
PIMZOS.COM	ACRO DIN-Rail Voeding AD1048-24FS (24VDC/2A)	41	1
PIMZOS.COM	Apparaatsnoer FWL Schuko Haaks, 1,8 meter, 3 x 0,	41	1
Mennegat Trading BV	Mag Audio AIR-C8-16-BK-W incl. muurbeugel	36	3
Jeannette Kershof	DermaBestÂ® Melavitil	31	1
Mennegat Trading BV	Powersoft MEZZO322A (0613)	27	2
Mennegat Trading BV	AtlasIED AZM4	23	2

Figure 3.17 - Zone A Required Storage Spaces

3.8.2 Zones F-I

Moving onto zones F, G, H, and I, the first step is to count the number of times each product has been ordered from April until July. Similarly to zone A, this is done by observing the order history on Excel and using the CountIF function in Excel to count the number of times each product has been picked in different orders.

Client	Product	Amount of times ordered
Pentair	HP housing 220 PVC-U	116
Pentair	S-225 FSFC housing	29
Pentair	XF40	21
Pentair	XF64	18

Figure 3.18 - Pentair Product Pick Amount

Figure 3.18 shows the four products in zones F, G, H, and I ranked from most ordered to least ordered. In addition, all the products in these zones belong to the client Pentair. The table shows that the most ordered product is “HP housing 220 PVC-U” with 116 orders since April.

The second step is to identify the required storage locations for the products. This is done by studying the location list and counting the number of locations for each product on Excel, similar to what is done in zone A. Figure 3.19 below shows an adjusted version of table 3.18, by including the required storage spaces/pallet places for each product.

Client	Product	Amount of times ordered	Pallet Places
Pentair	HP housing 220 PVC-U	116	43
Pentair	S-225 FSFC housing	29	22
Pentair	XF40	21	36
Pentair	XF64	18	27

Figure 3.19 - Pentair Required Storage Spaces

This section stops by identifying the required information needed to create the COI storage policy: the required storage space and the order amount for the products. Section 3.9 identifies the required information to create the OOS storage policy.

3.9 OOS Storage Policy

This section extracts the required information needed to produce the OOS storage policy: finding the products that are ordered most together for each client. This study is only done for zone A (e-commerce products) because orders for Pentair are single command orders, while orders for zone A are multi command. In addition, the order history is analyzed starting from January since starting from April did not provide enough interaction frequencies between the products.

Clients in Zone A
Jeanette Kershof
Mennegat
Mercis
Mr. GPS
PIMZOS
Bowiq

Table 3.2 - Zone A (E-commerce) Clients

Table 3.2 provides a recap of all the clients in zone A. The order history is studied to find the products, for each client, that are ordered together the most. These products can be stored closer together for shorter travel distances if they are not already.

	Vitipro	DermaBes	UVB-lichtt	UVB-lichtt	Kernel UV	UVB-lichttherapielamp Middel snoerloos
Vitipro	x					
DermaBestÂ® Melavitil	7	x				
UVB-lichttherapielamp Klein snoerloo	0	0	x			
UVB-lichttherapielamp klein	0	2	0	x		
Kernel UVB handlamp middel	0	2	0	0	x	
UVB-lichttherapielamp Middel snoerlc	1	3	0	0	0	x

Figure 3.20 - Jeanette Interaction Frequency

Beginning with Jeanette, a matrix is created for all the products, and then numbers are filled in, representing the number of times each product has interacted with another since January. Jeanette has relatively small amounts of products in zone A, thus it is easy to observe the order history and use Excel to count how many times the products appeared together in different orders. As can be seen, highlighted in yellow, the products “Vitipro” and “DermaBestÂ® Melavitil” are ordered in seven different orders together, making them the products that interacted with each other the most.

	AtlasIED A-	AtlasIED A:	AtlasIED A:	AtlasIED C-	AtlasIED C-	AtlasIED FS	AtlasIED W	AtlasIED X-	AtlasIED X-	BAS DigiBe	Centolight
AtlasIED A-BT-EU	x										
AtlasIED AZM4	3	x									
AtlasIED AZM8	1	3	x								
AtlasIED C-V-EU	0	0	0	x							
AtlasIED C-ZSV-EU	2	2	2	0	x						
AtlasIED FS12T-99	0	0	0	0	0	x					
AtlasIED WTSD-MIX31K	1	5	2	0	1	0	x				
AtlasIED X-ANS-EU	0	3	4	0	1	0	1	x			
AtlasIED X-ZPS paging mic	1	2	0	0	0	0	1	0	x		
BAS DigiBell - Schoolbel en Pa	0	1	0	0	0	0	0	0	0	x	
Centolight Clubwasher 360	0	0	0	0	0	0	0	0	0	0	x
Centolight Lightblaster 200	0	0	0	0	0	0	0	0	0	0	0
Centolight MOOD 1818WP, outdoor IP65, 18x18W RGBWA	0	1	0	0	0	0	1	0	0	0	0
Centolight Moodliner 1430WP	0	0	0	0	0	0	0	0	0	0	0

Figure 3.21 - Mennegat Interaction Frequency

Mennegat, on the other hand, has a large number of products, thus a code needs to be used to scan the order history and count the number of times the products are ordered together. Once all the numbers are filled in, another code is used to search for the highest number in the matrix and highlight it so that the products that interacted with each other the most can be identified. The highlighted number cannot be seen in Figure 3.21, because it is lower in the matrix. The rest of the table and the highlighted number can be found in Appendix C in Figure C.6. To summarize, the products that are ordered together the most are “Powersoft MEZZO604A (0610)” and “Powersoft WM TOUCH 4.3" zwart” with 10 orders. The VBA code used to do this can be found in the Excel file, ‘Mennegat OOS’ in Module 1, where the result of the code can be found in the worksheet, ‘Final’.

The same process is done for the rest of the clients, and the rest of the matrices are shown in Appendix C. Table 3.3 below summarizes the findings by showing the products ordered the most together per client. The clients Bowiq and Mercis are not included because their products had little to no interaction frequencies.

Client	Product 1	Product 2	Interaction Frequency
Jeanette	Vitipro	DermaBest ® Melavitil	7

PIMZOS	Power Cord Schuko 1,8 meter	IP POWER 9255GE	11
Mr. GPS	mrgps-draagtas	Zumo-xt2	13
Mennegat	Powersoft MEZZO604A (0610)	Powersoft WM TOUCH 4.3" zwart	10

Table 3.3 - Interaction Frequencies

To summarize, this chapter describes the current situation of the warehouse by explaining the current order picking process and providing information on the stock and their storage locations. Moreover, this chapter provides the information necessary to create the COI and the OOS storage assignment policies by scanning the order history and identifying important data such as how many times the products have been picked, their required storage space, and the interaction frequencies. The next chapter uses this information to create and implement the COI and OOS storage policies in the specified zones.

4. Formulating a Solution

In this section, the findings from sections 3.8 and 3.9 are implemented to create and implement the COI and OOS storage policies. These new storage assignment policies reorganize zones A, F, G, H, and I to decrease the distance traveled when picking orders. In this chapter, section 4.1 creates the COI storage policy for single command order picking, while section 4.2 creates the OOS storage policy for multi command order picking

4.1 Implementing the COI Storage Policy

As discussed in Section 2, the cube per order index is the ratio of a product's storage space requirement to the number of times this product is picked in different orders (Malmborg & Bhaskaran, 1990). In addition, this policy works best when dealing with single command order picking (Schuur, 2015). According to Schuur (2015), the COI policy consists of three steps. Figure 4.1 shows these below.

Figure 4.1 - Three steps of COI allocation

4.1.1 Step 1: Ranking Locations

The first step is simple for the zones. Each zone has racks numbered from 1 to 21, where one is the closest to the dock doors (I/O point) and 21 is the furthest. Thus, the first rack is ranked as the best location due to its proximity to the I/O point, while the 21st rack is ranked as the worst due to its long distance to the I/O point. This applies to all zones A, F, G, H, and I.

4.1.2 Step 2: Ranking Products in Zone A

Beginning with zone A, step 2 uses the information provided in section 3.8 to calculate the COI ratios of the products and rank them from the lowest ratios to the highest (best to worst).

Client	Product	Amount of times ordered	Pallet Places	COI Ratio
PIMZOS.COM	PT100 Outdoor Sensor, Class A, 3-wire	165	1	0.006060606
Mennegat Trading BV	SONORA-6TN (Black)	156	2	0.012820513
Mennegat Trading BV	Helvia Internetradio OMNIS-100	128	2	0.015625
PIMZOS.COM	LabJack U3-LV	60	1	0.016666667
PIMZOS.COM	EX9520R	58	1	0.017241379
Mennegat Trading BV	Powersoft WM TOUCH 4.3" zwart	58	1	0.017241379
PIMZOS.COM	Power Cord Schuko 1,8 meter - VDE - Schuko to C13 - Black	56	1	0.017857143
PIMZOS.COM	PFH16240	55	1	0.018181818
PIMZOS.COM	IP POWER 9255GE	53	1	0.018867925
Mennegat Trading BV	Powersoft MEZZO602A (0611)	50	1	0.02
Mennegat Trading BV	Fonestar SONORA-6TB (White)	48	1	0.020833333
Jeannette Kershof	Vitipro	42	1	0.023809524
PIMZOS.COM	ACRO DIN-Rail Voeding AD1048-24FS (24VDC/2A)	41	1	0.024390244
PIMZOS.COM	Apparaatsnoer FWL Schuko Haaks, 1,8 meter, 3 x 0,	41	1	0.024390244
Mennegat Trading BV	Powersoft MEZZO604A (0610)	65	2	0.030769231

Figure 4.2 - Zone A COI Ranking

As can be seen in Figure 4.2, the COI ratio is calculated for all the products in zone A by dividing the number of pallet places by the number of times the products have been picked/ordered. Then, the products were ranked with the lowest ratios being the best and the highest being the worst.

4.1.3 Step 2: Ranking Products in Zones F-I

Doing the same process for the products in zones F-I, the COI ratios are calculated for each product. In Figure 4.3, the products are ranked according to their COI ratios.

Client	Product	Amount of times ordered	Pallet Places	COI Ratio
Pentair	HP housing 220 PVC-U	116	43	0.37068966
Pentair	S-225 FSFC housing	29	22	0.75862069
Pentair	XF64	18	27	1.5
Pentair	XF40	21	36	1.71428571

Figure 4.3 - Pentair COI Ranking

4.1.4 Step 3: Linking Products with Locations (Toy Problem)

Next, looking at Step 3, the ranked products must be linked with the ranked locations. As previously mentioned, the best locations start from the first racks since these are closest to the I/O points. Thus, the products with the lowest COI ratios are linked with the first racks, and the products with the highest COI ratios are linked with the last racks. Figure 4.4 shows a 'toy' version of the problem for a better understanding.

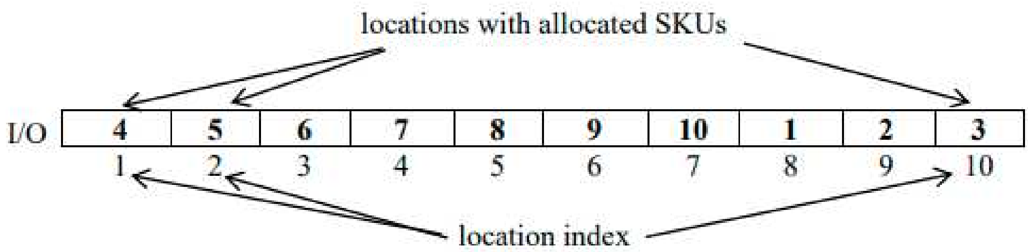


Figure 4.4 - Simple Allocation Problem (Schuur, 2015).

As can be seen in the figure, the numbers inside the cells represent the SKUs/products and the numbers below them are the storage locations (1-10). In addition, the first storage location is closest to the I/O point, and the last storage location (10) is the furthest away. Moreover, the products with the lowest COI ratios are stored in the first locations, and the products with the highest ratios are stored at the end. In Figure 4.4, for example, product number 4 has the lowest COI ratio, while product number 3 has the highest.

4.1.5 Step 3: Linking Products with Locations in Zone A

Locations
A01A00
A01A10
A01A20
A01A30
A01A40
A01B00
A01B10
A01B20
A01B30
A01B40
A01C00

Figure 4.5 - Storage Locations

Implementing the simple allocation problem discussed in 4.1.4 to zone A, the ranked products are linked to the ranked locations depending on their COI ratios and their required storage space. Figure 4.5 shows a list of the storage locations in zone A beginning from the location closest to the I/O point to the one furthest away. Before these locations are linked with the ranked products, these locations are split up into pick and bulk areas, per management's request, to make order picking quicker and more efficient.

In zone A of the warehouse, levels 00 and 10 (storage locations ending with "00" or "10") are pick areas, and levels 20, 30, and 40 are bulk areas. A code is created on VBA to assign the locations to the ranked products depending on how many pallet places they need. In addition, the code makes sure that a product's initial storage location is always a pick area so that fast movers are never stored in the bulk area. They can have reserves there but their primary locations should always be the pick area. As a result, the code assigns, for every product, only one pallet place in the pick area, and the rest of the locations are in the bulk areas. Once the pick locations run out, the other products, at the very bottom of the table, are directly stored in bulk locations. Additionally, the required amount of storage space, for every product, is constant and unchanged throughout the report.

Client	Product	Amount of times ordered	Pallet Places	COI Ratio	Locations
PIMZOS.COM	PT100 Outdoor Sensor, Class A, 3-wire	165	1	0.006060606	A01A00,
Mennegat Trading BV	SONORA-6TN (Black)	156	2	0.012820513	A01A10, A01A20
Mennegat Trading BV	Helvia Internetradio OMNIS-100	128	2	0.015625	A01B00, A01A30
PIMZOS.COM	LabJack U3-LV	60	1	0.016666667	A01B10
PIMZOS.COM	EX9520R	58	1	0.017241379	A01C00
Mennegat Trading BV	Powersoft WM TOUCH 4.3" zwart	58	1	0.017241379	A01C10
PIMZOS.COM	Power Cord Schuko 1,8 meter - VDE - Schuko to C13 - Black	56	1	0.017857143	A01D00
PIMZOS.COM	PFH16240	55	1	0.018181818	A01D10
PIMZOS.COM	IP POWER 9255GE	53	1	0.018867925	A02A00
Mennegat Trading BV	Powersoft MEZZO602A (0611)	50	1	0.02	A02A10
Mennegat Trading BV	Fonestar SONORA-6TB (White)	48	1	0.020833333	A02B00

Figure 4.6 - Zone A Location Assignment

Figure 4.6 shows the result of the code where the products are given locations according to their COI ratio ranking and storage space requirement. In addition, the products' first locations are always in the pick area, represented by levels 00 or 10. If they require more than one pallet place, the other storage locations are reserves of this product and are in the bulk area. The VBA code used to do this can be found in the Excel file 'Zone A' in Module 3. The output of the code is found in the worksheet 'COI'. The reason why, for every product, only one pallet place is stored in the pick area is because as stated in Chapter 2, Van Den Berg et al. (1998) suggest that if too many products are stored in the pick area large distances would be traveled and large orders would become too expensive. Thus, having only one pallet place, for each product, in the pick area ensures that travel distance is kept minimal.

4.1.6 Step 3: Linking Products with Locations in Zones F-I

Carrying out the same procedure for Pentair's products, in zones F-I, the products are given locations depending on their COI ratios and required storage space. Here, however, a distinction is not made between pick and bulk locations since all the products are stored in high locations in the racks (level 30 and above), and a forklift is always used due to their heavy loads.

Locations
F01A30
F01A40
F01A50
G01A30
G01A40
G01A50
H01A30
H01A40
H01A50
I01A30

Figure 4.7 - Zones F-I Storage Locations

Figure 4.7 shows a list of storage locations in zones F-I beginning from the location closest to the I/O point to the one furthest away. Then a similar VBA code is used to the one used for zone A to assign locations to the products depending on their COI ratios and their required storage space.

Client	Product	Amount of tim	Pallet Places	COI Ratio	Locations
Pentair	HP housing 220 PVC-U	116	43	0.370689655	F01A30, F01A40, F01A50, G01A30, G01A40, G01A50,
Pentair	S-225 FSFC housing	29	22	0.75862069	H01D40, H01D50, I01D30, I01D40, I01D50, F02A30, I
Pentair	XF64	18	27	1.5	G02B50, H02B30, H02B40, H02B50, I02B30, I02B40,
Pentair	XF40	21	36	1.714285714	H02D50, I02D30, I02D40, I02D50, F03A30, F03A40, F

Figure 4.8 - Zones F-I Location Assignment

Figure 4.8 shows the result of the code, where every product is assigned locations depending on their COI ratios and their required storage space. The VBA code used here can be found in the Excel file "Zones F-I" in Module 1, where the output of the code is in the worksheet "Sheet1".

To summarize, section 4.1 uses the information provided in sections 3.8 and 3.9 to create and implement the COI storage assignment policy for zones A, F, G, H, and I. This is done in three steps: first, the locations for all the zones are ranked from best to worst, where the best locations are the locations closest to the I/O point and the worst are the locations furthest away. Second, the COI ratios are calculated for all the products and they are ranked accordingly. The products with the lowest ratios are the best and the products with the highest ratios are the worst. Finally, in step three, the best products are linked with the best locations, and the worst products are linked with the worst locations. This is done by creating a VBA code that takes the ranked products and assigns them locations depending on their required storage space. For zone A, each product is given only one location in the pick area to ensure minimal travel distance, and their reserves are stored in bulk locations where they can be replenished when needed. Additionally, once the pick locations run out, the products at the end of the table are stored directly in the bulk area as they are 'dead stock'. The next section improves the created storage policy for zone A by adding on the OOS storage policy to see if products that are frequently ordered together can be brought closer to each other. Zones F, G, H, and I, however, are left unchanged, since they are only single command orders.

4.2 Implementing the OOS Storage Policy

This section uses the provided information in section 3.9 to create and implement the OOS storage policy for zone A.

Client	Product 1	Product 2	Interaction Frequency
Jeanette	Vitipro	DermaBest ® Melavitil	7
PIMZOS	Power Cord Schuko 1,8 meter	IP POWER 9255GE	11
Mr. GPS	mrgps-draagtas	Zumo-xt2	13
Mennegat	Powersoft MEZZO604A (0610)	Powersoft WM TOUCH 4.3" zwart	10

Table 4.1 - Interaction Frequencies (2)

To recall the results, Table 4.1 presents the findings of section 3.9. The table shows the two products that were ordered the most together since January for all the clients in zone A. The 'interaction frequency' is how many times they have been ordered together. To implement this, these products must be stored closer together, if they are not already.

Client	Product	Amount of times ordered	Pallet Places	COI Ratio	Locations
PIMZOS.COM	PT100 Outdoor Sensor, Class A, 3-wire	165	1	0.006060606	A01A00,
Mennegat Trading BV	SONORA-6TN (Black)	156	2	0.012820513	A01A10, A01A20
Mennegat Trading BV	Helvia Internetradio OMNIS-100	128	2	0.015625	A01B00, A01A30
PIMZOS.COM	LabJack U3-LV	60	1	0.016666667	A01B10
PIMZOS.COM	EX9520R	58	1	0.017241379	A01C00
Mennegat Trading BV	Powersoft WM TOUCH 4.3" zwart	58	1	0.017241379	A01C10
PIMZOS.COM	Power Cord Schuko 1,8 meter - VDE - Schuko to C13 - Black	56	1	0.017857143	A01D00
PIMZOS.COM	PFH16240	55	1	0.018181818	A01D10
PIMZOS.COM	IP POWER 9255GE	53	1	0.018867925	A02A00
Mennegat Trading BV	Powersoft MEZZO602A (0611)	50	1	0.02	A02A10
Mennegat Trading BV	Fonestar SONORA-6TB (White)	48	1	0.020833333	A02B00
Jeannette Kershof	Vitipro	42	1	0.023809524	A02B10
PIMZOS.COM	ACRO DIN-Rail Voeding AD1048-24FS (24VDC/2A)	41	1	0.024390244	A02C00
PIMZOS.COM	Apparaatsnoer FWL Schuko Haaks, 1,8 meter, 3 x 0,	41	1	0.024390244	A02C10
Mennegat Trading BV	Powersoft MEZZO604A (0610)	65	2	0.030769231	A02D00, A01A40
Jeannette Kershof	DermaBestÂ® Melavitil	31	1	0.032258065	A02D10
Mennegat Trading BV	AtlasIED X ANS EU	22	1	0.045454545	A03A00

Figure 4.9 - Zone A Location Assignment (2)

Figure 4.9 highlights the products mentioned in Table 4.1 in different colors to identify where these products are located in the Excel table and to distinguish the clients from each other. A legend can be found in Appendix D explaining which colors represent which clients. To summarize, the color yellow represents the client Mennegat, blue represents PIMZOS, red represents Jeanette, and green represents Mr. GPS.

Client	Product	Amount of times ordered	Pallet Places	COI Ratio	Locations
PIMZOS.COM	PT100 Outdoor Sensor, Class A, 3-wire	165	1	0.006060606	A01A00,
Mennegat Trading BV	SONORA-6TN (Black)	156	2	0.012820513	A01A10, A01A20
Mennegat Trading BV	Helvia Internetradio OMNIS-100	128	2	0.015625	A01B00, A01A30
PIMZOS.COM	LabJack U3-LV	60	1	0.016666667	A01B10
PIMZOS.COM	EX9520R	58	1	0.017241379	A01C00
Mennegat Trading BV	Powersoft WM TOUCH 4.3" zwart	58	1	0.017241379	A01C10
Mennegat Trading BV	Powersoft MEZZO604A (0610)	65	2	0.030769231	A02D00, A01A40
PIMZOS.COM	Power Cord Schuko 1,8 meter - VDE - Schuko to C13 - Black	56	1	0.017857143	A01D00
PIMZOS.COM	IP POWER 9255GE	53	1	0.018867925	A02A00
PIMZOS.COM	PFH16240	55	1	0.018181818	A01D10
Mennegat Trading BV	Powersoft MEZZO602A (0611)	50	1	0.02	A02A10
Mennegat Trading BV	Fonestar SONORA-6TB (White)	48	1	0.020833333	A02B00
Jeannette Kershof	Vitipro	42	1	0.023809524	A02B10
Jeannette Kershof	DermaBestÂ® Melavitil	31	1	0.032258065	A02D10
PIMZOS.COM	ACRO DIN-Rail Voeding AD1048-24FS (24VDC/2A)	41	1	0.024390244	A02C00

Figure 4.10 - Zone A Location Assignment (3)

To bring the products closer to each other, their positions are changed so that every pair exists one after the other. This is shown in Figure 4.10. Finally, the VBA code used in section 4.1.5 for the COI policy is used again to assign storage locations to the products with this new order/ranking. As a result of this, the products are given new locations where they are closer together. Figure 4.11 shows the result of re-executing the code.

Client	Product	Amount of times ordered	Pallet Places	COI Ratio	Locations
PIMZOS.COM	PT100 Outdoor Sensor, Class A, 3-wire	165	1	0.006060606	A01A00,
Mennegat Trading BV	SONORA-6TN (Black)	156	2	0.012820513	A01A10, A01A20
Mennegat Trading BV	Helvia Internetradio OMNIS-100	128	2	0.015625	A01B00, A01A30
PIMZOS.COM	LabJack U3-LV	60	1	0.016666667	A01B10
PIMZOS.COM	EX9520R	58	1	0.017241379	A01C00
Mennegat Trading BV	Powersoft WM TOUCH 4.3" zwart	58	1	0.017241379	A01C10
Mennegat Trading BV	Powersoft MEZZO604A (0610)	65	2	0.030769231	A01D00, A01A40
PIMZOS.COM	Power Cord Schuko 1,8 meter - VDE - Schuko to C13 - Black	56	1	0.017857143	A01D10
PIMZOS.COM	IP POWER 9255GE	53	1	0.018867925	A02A00
PIMZOS.COM	PFH16240	55	1	0.018181818	A02A10
Mennegat Trading BV	Powersoft MEZZO602A (0611)	50	1	0.02	A02B00
Mennegat Trading BV	Fonestar SONORA-6TB (White)	48	1	0.020833333	A02B10
Jeannette Kershof	Vitipro	42	1	0.023809524	A02C00
Jeannette Kershof	DermaBestÂ® Melavitil	31	1	0.032258065	A02C10
PIMZOS.COM	ACRO DIN-Rail Voeding AD1048-24FS (24VDC/2A)	41	1	0.024390244	A02D00

Figure 4.11 - Zone A Location Assignment (4)

To summarize, section 4.2 uses the provided information in section 3.9 to create and implement the OOS storage policy in zone A of the warehouse. This was done by first identifying the products that were ordered the most together for every client. Second, these products were highlighted in the location assignment table of zone A and were brought closer together so that they could have new locations where they were closer together. Third, the code used for the COI storage policy for zone A in section 4.1 was re-executed after the products' positions were changed, to give them new locations where they are closer together. All in all, this chapter uses the provided information in Chapter 3 to create and implement the COI and OOS storage assignment policies for shorter travel distances when order picking. The effect of the new storage assignment policies is tested in the next chapter when calculating the travel distance it takes to complete a set of large orders using the new layout against the old/current one.

5. Evaluation of Solution and Results

This section tests the new storage assignment policies by calculating the total distance traveled when picking a series of large orders. To calculate this, a sketch is first created of the warehouse, using Excel in section 5.1. Section 5.2 then uses this sketch to calculate the travel distance when completing these large orders using the current storage assignment policy. Section 5.3 on the other hand, calculates the same distance but using the new storage assignment policy. Finally, a comparison is made of the results and a conclusion is drawn in section 5.4.

5.1 Warehouse Sketch

To start, a sketch of the warehouse is drawn in Excel to visualize the current layout.

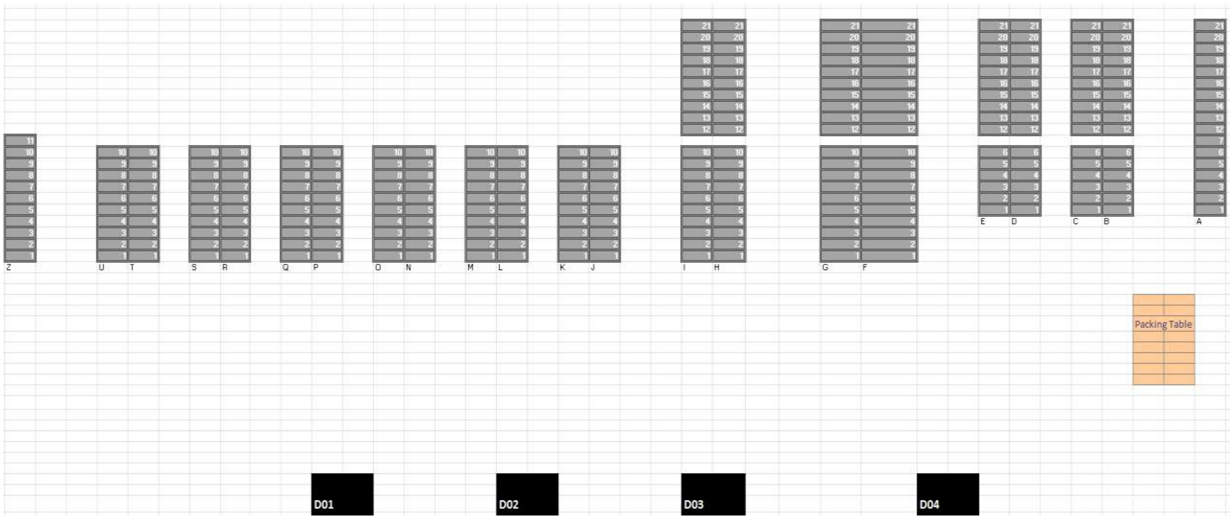


Figure 5.1 - Warehouse Sketch

Figure 5.1 shows an approximate sketch of the warehouse. This sketch is used to calculate the distance traveled. It is important to note that this sketch only poses as an approximate visual of reality and the proportions used here are not to scale. To help measure the distance traveled, each cell (white box) represents 1 meter. The next step is to collect a couple of orders to analyze.

To create a list of large orders, the order history is studied, from January until July, using the warehouse management system. When looking at orders, it is filtered such that the biggest orders since January can be seen including the fast-moving products and the products that have been brought closer together. This aids in the comparison of the old and new storage assignment policies.

Orders	Client	Product	Amoun	Current loc	New loc
1	PIMZOS	PT100 Outdoor Sensor, Class A, 3-wire	2	A14D20.2	A01A00
2	PIMZOS	IP POWER 9255GE	2	A12A00	A02A00
2	PIMZOS	Power Cord Schuko 1,8 meter - VDE - Schuko to C13 - Bla	1	A12A20.2	A01D10
2	PIMZOS	LabJack U3-HV	1	A15A20.1	A03C10
3	Jeanette	Vitipro	1	A12B00.1	A02C00
3	Jeanette	DermaBest ® Melavitil	1	A01C00	A02C10
4	Mennegat	Powersoft MEZZO604A (0610)	2	A17B00	A01D00
4	Mennegat	Powersoft WM TOUCH 4.3" zwart	1	A16C10.2	A01C10
4	Mennegat	Powersoft MEZZO324A (0612)	1	A05A10	A05B00
4	Mennegat	BAS Projector Speaker Industrial	2	Z02A20	A12D00
4	Mennegat	Helvia Internetradio OMNIS-100	1	A04C00	A01B00
4	Mennegat	SONORA-6TN (Black)	1	Z02D20	A01A10
4	Mennegat	Fonestar SONORA-8TN (Black)	1	A05B20	A15A00
5	Bowiq	BoCoustic Coat	1	A18B00	A14D10
5	Bowiq	BoCoustic base	1	A19A00	A15B10
5	Bowiq	BoCoustic finish	2	A20A00	A17B00
6	Mr. GPS	mrgps-draagtas	2	A01A00	A05A00
6	Mr. GPS	Zumo-xt2	1	A12B10.2	A05A10
7	Pentair	HP housing 220 PVC-U	1	F12A50	F01A30
7	Pentair	HP housing 220 PVC-U	1	F12B50	F01A40
7	Pentair	HP housing 220 PVC-U	1	F12D50	F01A50

Figure 5.2 - Large orders since January

Figure 5.2 shows a list of seven different orders. Order 1, for example, is not large, but it will aid in comparing the distance traveled when picking the most ordered product in zone A using both storage policies. Order 4, on the other hand, is a large order for Mennegat, demanding a total of seven products, with different amounts of each. This is an interesting order to analyze since it contains Mennegat's most ordered products, as well as the products currently stored in zone Z. The rest of the orders are all of the largest orders, for each client, since January. In addition, the last two columns show the current and new locations of every product.

5.2 Current Storage Assignment Policy

Now that the orders have been identified, the next step is to calculate the distance traveled by the order picker using the sketch created in section 5.1 and using the current storage assignment policy. This section uses the orders as well as the current locations of the products to demonstrate a visual of the order-picking route traveled by the order picker. Using a return routing policy and making every white cell equal to one meter, the total distance is calculated.

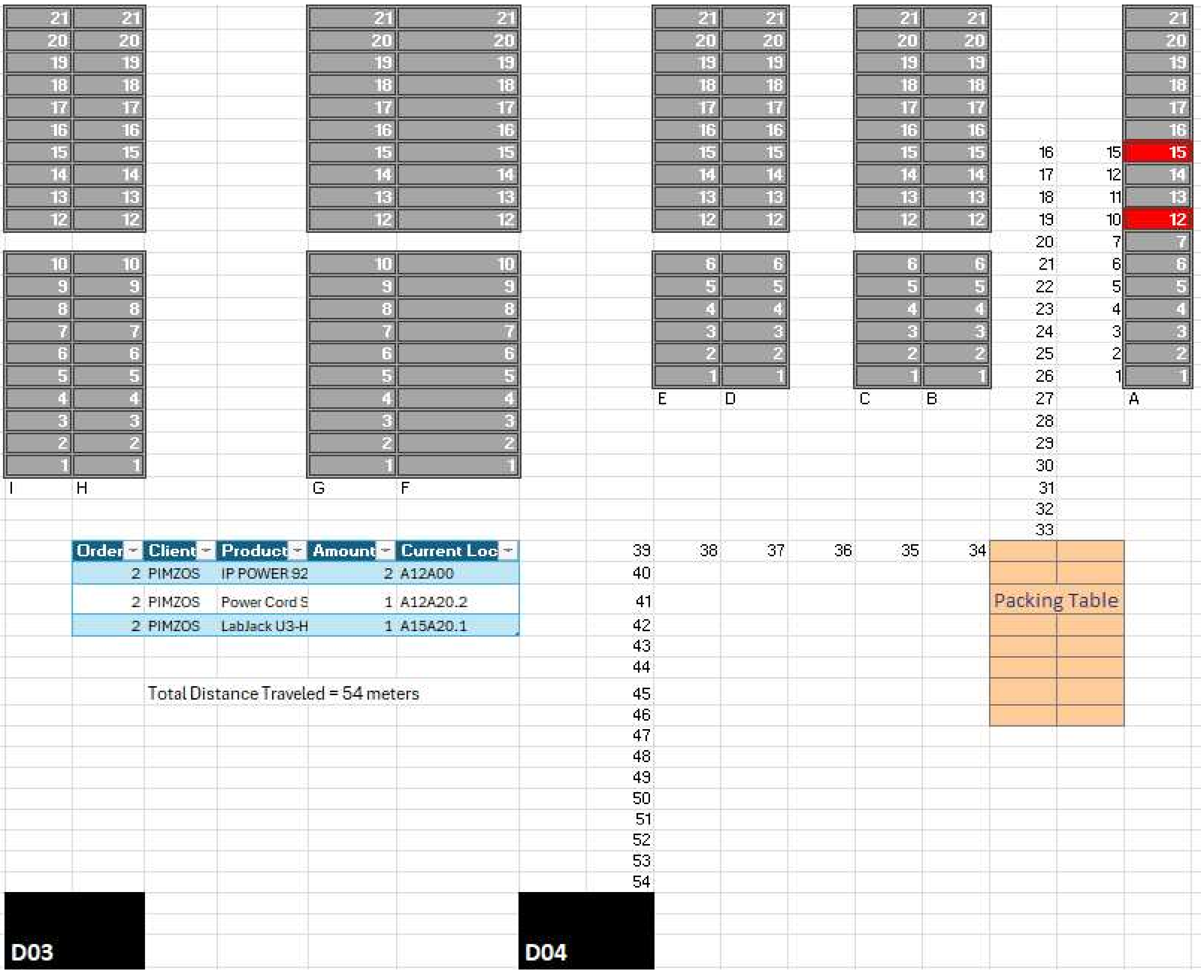


Figure 5.3 - Distance Traveled to Pick Order 2 Using the Current Storage Policy

Figure 5.3 shows an example of the distance traveled to pick up order 2, using the current storage assignment policy. To measure the distance traveled, a set of constant assumptions and constraints had to be made. For example, in every new order, the order picker's starting position is always the first rack in the zone of the first product to be picked. In this example, the first product to be picked is in zone A, thus the order picker starts in in the first rack of zone A. In addition, a distinction is not made between the different horizontal locations in a rack, such as A, B, C, and D. They all have the same distance as long as they are in the same rack. A distinction is only made for the different vertical locations, such as levels “00” to “40” since these determine whether a product is in a pick or bulk location, or whether a forklift must be used. In Figure 5.3, a table can be seen of the list of products needed to be picked. The second and third products are stored in bulk locations, thus three meters are added to the distance whenever the order picker reaches their locations to reflect the use of a forklift. This is kept as a standard for every order. Three meters are added to the distance regardless of which bulk location a product is in (“20”, “30”, and “40”). They are all the same. In addition, a distinction is not made regarding the amount of items/products that need to be picked for e-commerce clients. This is because their products are usually small and an order picker can pick several amounts of each product in one trip. Thus, no extra distance is traveled if more than one product of an e-commerce client needs to be picked. This leads to the assumption that all e-commerce client orders can be picked up in one trip. In Figure 5.3, once the order picker is finished picking all of the products he must first go to the packing table before he can go to the dock doors.

The final assumption is that a distinction is not made between the different dock doors (no different order lines). The order picker can go to the nearest dock door out of the four from whichever position he is standing in. In the end, the order picker in Figure 5.3 travels 53 meters to complete order 2.

Figure 5.4 - Distance Traveled to Pick Order 4 Using the Current Storage Policy

Figure 5.4 shows another example of an order being picked using the current storage assignment policy, but this time it is a bigger order. This order is for Mennegat and demonstrates the effects of having one of the most ordered products stored at the other end of the warehouse, in zone Z. As can be seen, large distances are traveled. The order picker first goes to rack 4, in zone A, to pick a product. Then, he must travel to rack 5 to pick two products: the first one is in a pick location ("10") and the second one is not, therefore a forklift must be used. That is why an additional three meters are added once the order picker is in rack number 5. He then picks the following two products in racks 16 and 17. Before heading to the packing table, the order picker must travel to zone Z to pick up the last two remaining products, in rack number 2, in bulk locations. Three additional meters are added when he reaches the second rack in zone Z. After this, he travels to the packing table and then to the dock doors. In the end, the order picker travels a significant 130 meters.

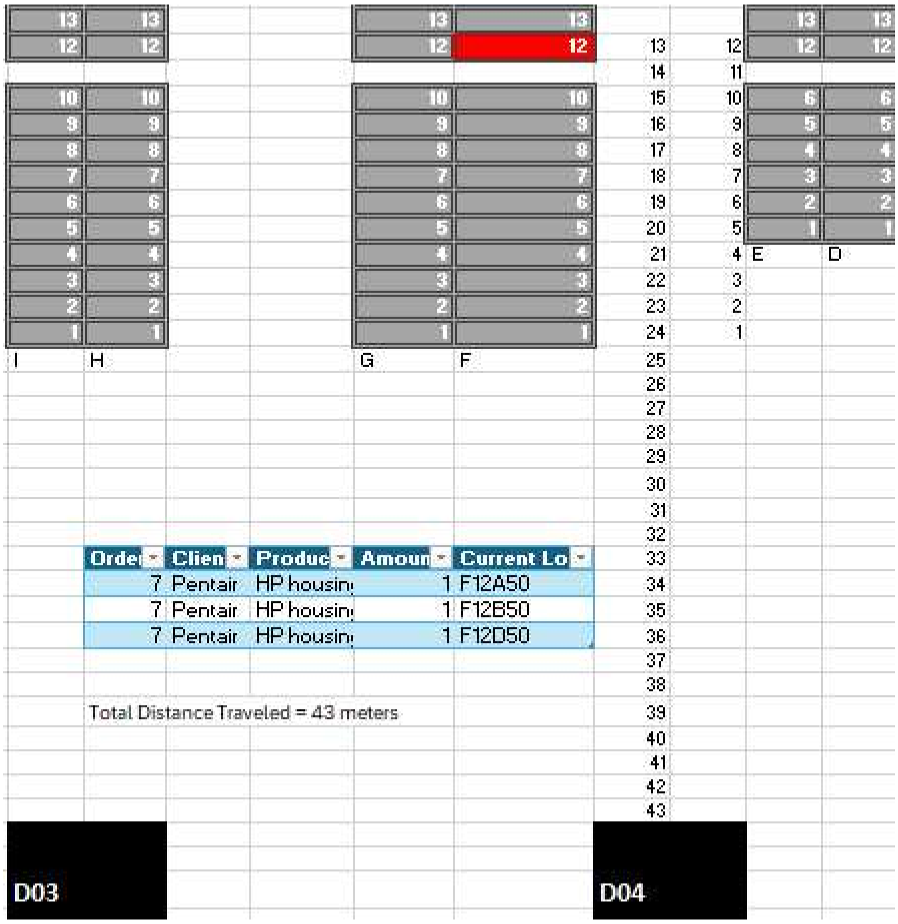


Figure 5.5 - Distance Traveled to Pick Order 7 Using the Current Storage Policy

Figure 5.5 shows the final example, using order 7 of Pentair. As can seen in the table, the order requires three amounts of the product, “HP housing 220 PVC-U” each in different locations. Here, a few things change regarding how the distance is calculated compared to the e-commerce orders. Firstly, each product that needs to be picked up is equivalent to the number of trips needed to be made since one product equals one pallet load. An order picker cannot pick up more than one pallet per trip. Thus, three trips have to be made since he must pick three pallets/products. In addition, the order picker here uses a picking truck instead of walking on his feet. This eliminates the addition of three meters since all Pentair products are in high-level locations, and a truck must be used anyway. Finally, the order picker does not need to visit the packing table before going to the closest dock door. As can be seen in the figure, the first pick-up location is in the 12th rack of zone F, on the 50th level. The order picker picks up the first pallet and drives to the dock door to set it down having traveled a total of 43 meters in his first trip.

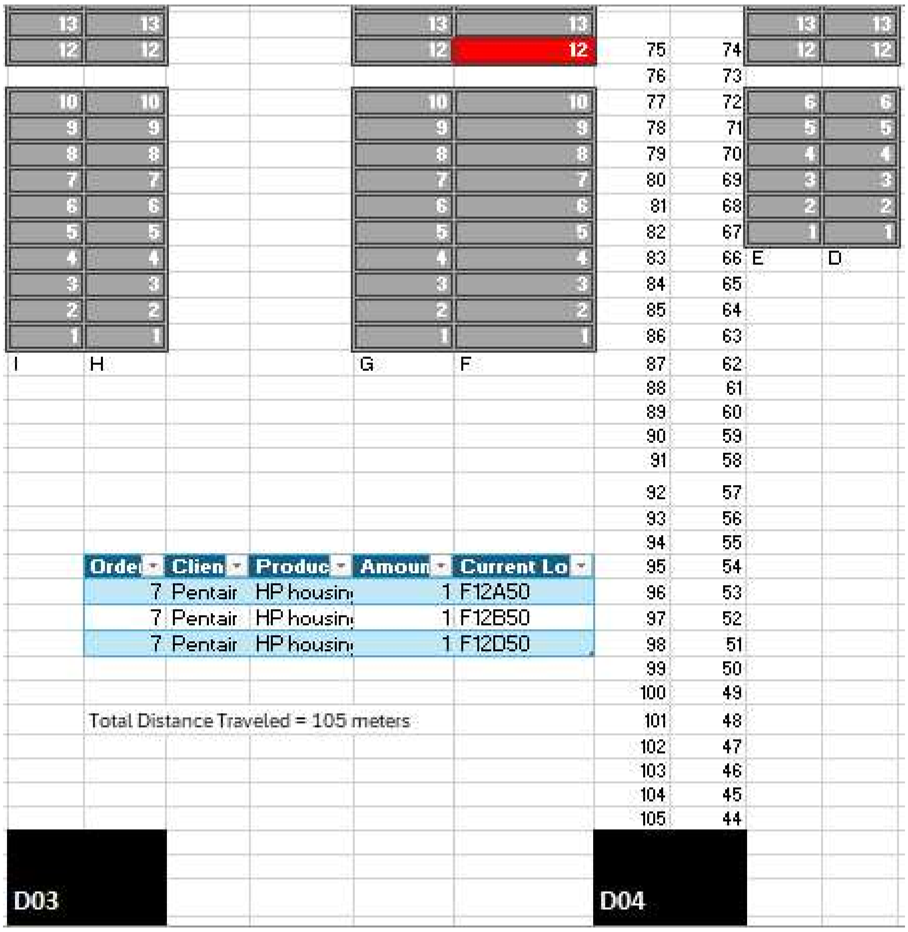


Figure 5.6 - Distance Traveled to Pick Order 7 Using the Current Storage Policy (2)

Figure 5.6 shows the same order, but this time for the second trip. The order picker starts at meter 44, near the dock door, drives again to the 12th rack in zone F to pick up the second pallet, and then drives back to the dock doors, completing a total of 105 meters for both trips one and two.

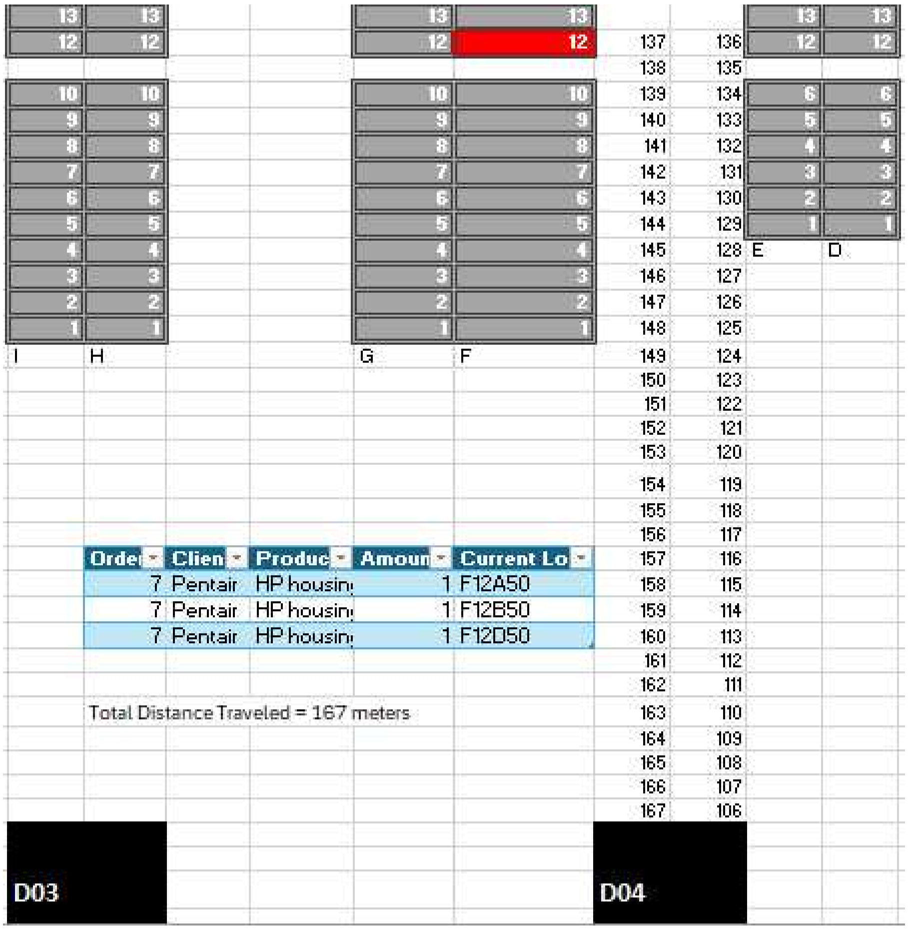


Figure 5.7 - Distance Traveled to Pick Order 7 Using the Current Storage Policy (3)

Finally, figure 5.7 shows the third and final trip of the order picker. Again, he starts near the dock door at meter 106, drives to the 12th rack in zone F, picks up the third and final pallet, and returns to the dock door having completed order 7 at a total of 167 meters traveled. What can be learned from this, is that all Pentair products are stored on the back racks of zone F-I causing huge distances to be traveled and wasted. The sketches for the rest of the orders can be found in the Excel file 'Warehouse Sketch - Distances'.

Order	Client	Distance Traveled
1	PIMZOS	50 meters
2	PIMZOS	54 meters
3	Jeanette	44 meters
4	Mennegat	130 meters
5	Bowiq	60 meters
6	Mr. GPS	44 meters
7	Pentair	167 meters

Total	-	549 meters

Table 5.1 - Distance Traveled for All Orders

To summarize, section 5.2 uses the warehouse sketch and the set of large orders created in section 5.1 to calculate the distance traveled using the current storage assignment policy. The sketches for the rest of the orders can be found in the Excel file 'Warehouse Sketch - Distances'. Table 5.1 summarizes the findings by showing the distance traveled for each order, and the total distance traveled for all the orders. The next section does the same but uses the new storage assignment policy.

5.3 New Storage Assignment Policy

In this section, the same orders are used to calculate the distance traveled, but this time using the new storage assignment policies. These are the new locations given to the products in Chapter 4, where zone A used a combination of the COI and OOS storage policies, and zones F, G, H, and I only used the COI policy due to single command order picking. In addition, the same assumptions and constraints apply here when calculating the distance.

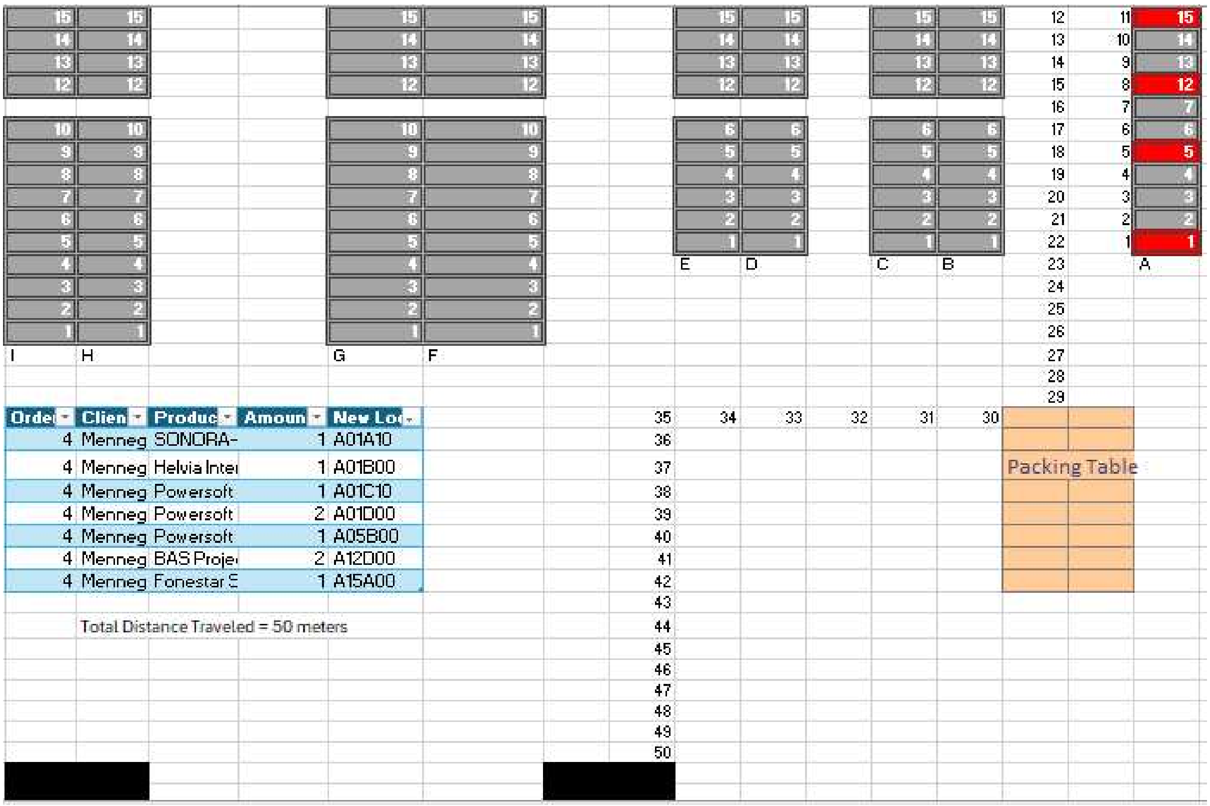


Figure 5.8 - Distance Traveled to Pick Order 4 Using the New Storage Policy

The first example of this section is shown in Figure 5.8, which picks order 4, of Mennegat, using the new storage assignment policy. This time all of the products are in zone A, and not in zone Z. The order picker first goes to the first rack to pick the first four products. Then, he travels to the fifth rack to pick the fifth product and then goes to racks 12 and 15 to pick the sixth and seventh products. This is already a big improvement for several reasons. Firstly, there are no products stored in zone Z.

Secondly, all of the products are close together, especially the ones that frequently interact, and all of the products are stored in pick locations, without needing to use a forklift. If Figure 5.8 and Figure 5.4 are compared, the result is a much simpler route for the order picker. In the end, the order picker travels only 50 meters, which is an 80-meter difference between the two storage policies.

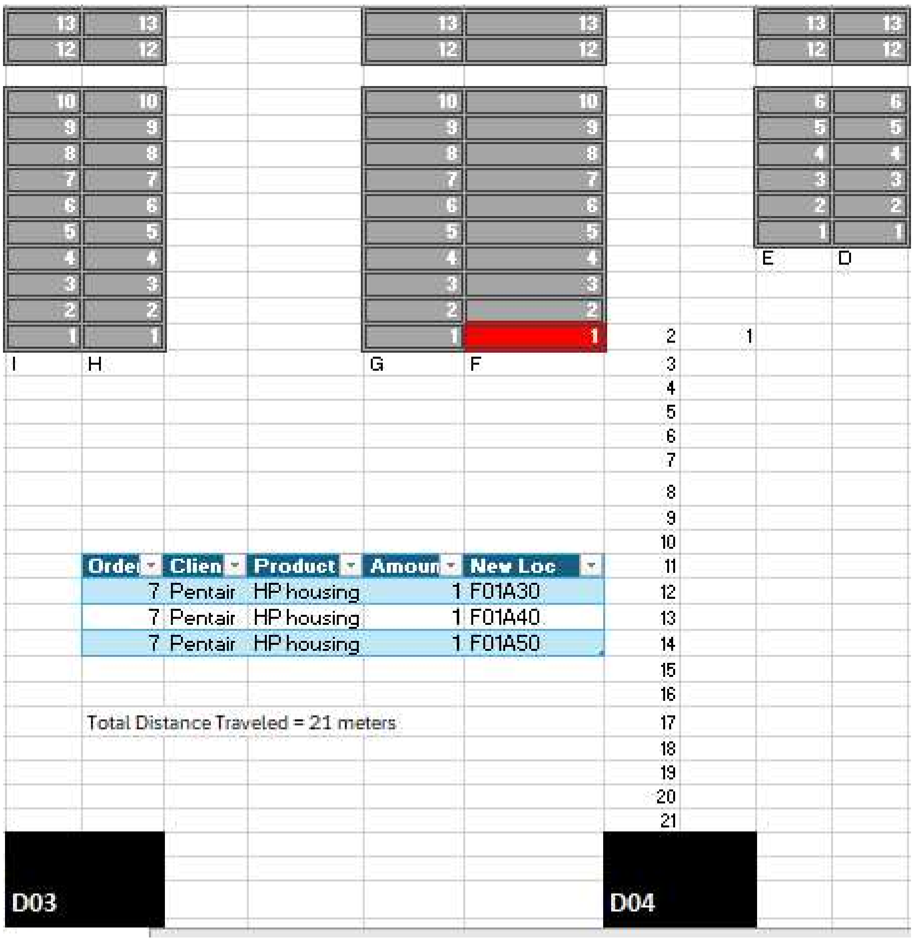


Figure 5.9 - Distance Traveled to Pick Order 7 Using the New Storage Policy

Figure 5.9 shows the second example of the distance traveled using the new storage policy. This example calculates the distance for order 7, Pentair. As can be seen in the table, the first location of the product is in the first rack of zone F, thus the order picker's starting position is the first rack there. He picks the pallet, and returns to the dock door, traveling a total of 21 meters in his first trip. This is already a big improvement since the pallets are very close to the dock doors, and he must not always go to the other side of the warehouse to pick the pallets.

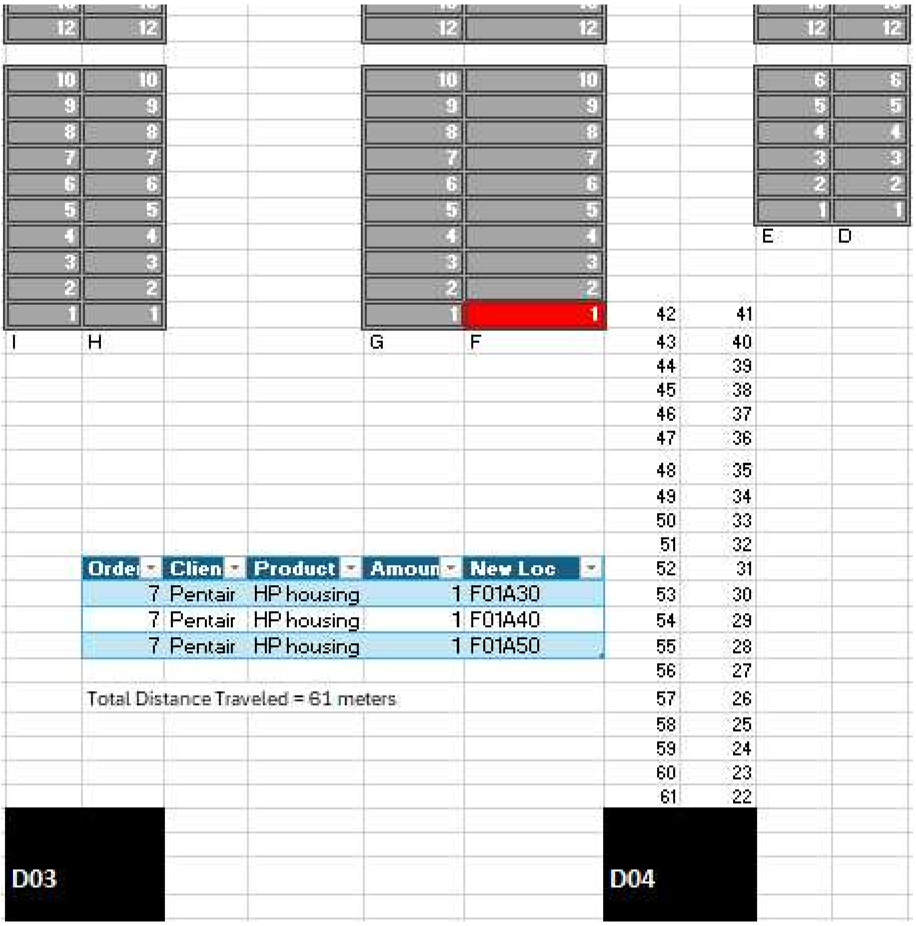


Figure 5.10 - Distance Traveled to Pick Order 7 Using the New Storage Policy (2)

Figure 5.10 shows the second trip. The order picker starts at meter 22, near the dock door where he had previously set down the first pallet. He then drives again to the first rack of zone F, picks the second pallet, and drives back to the dock doors, traveling a total of 61 meters for both trips.

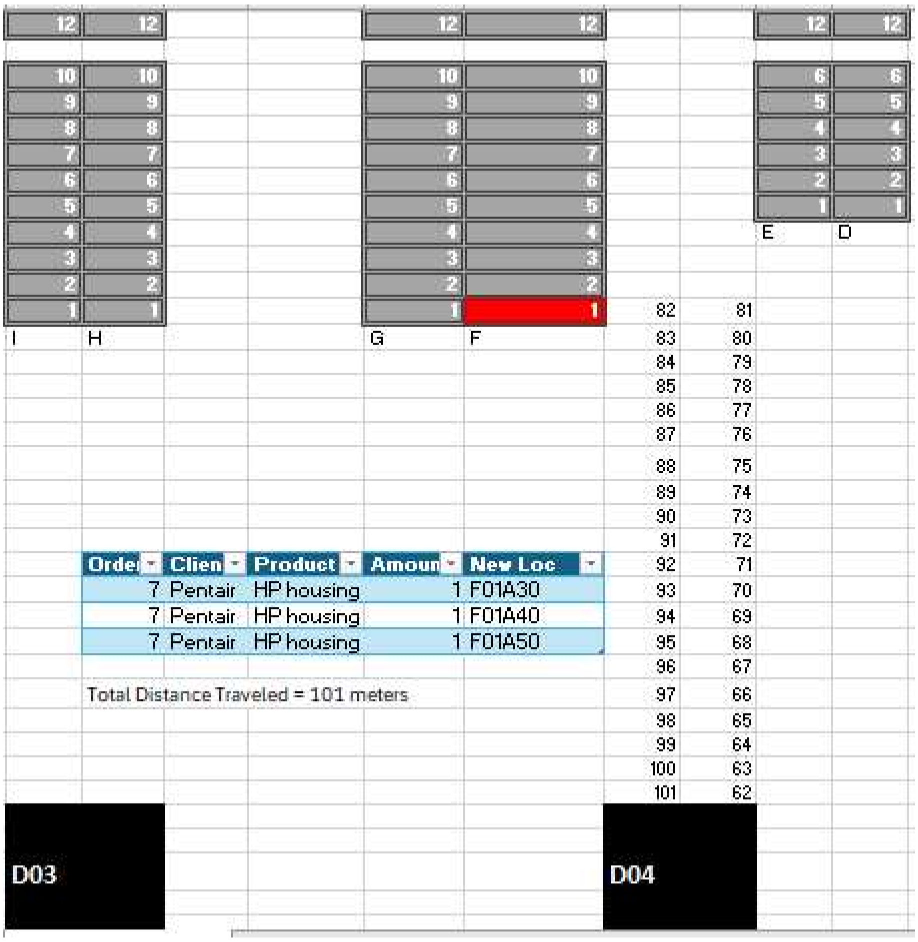


Figure 5.11 - Distance Traveled to Pick Order 7 Using the New Storage Policy (3)

Figure 5.11 shows the third and final trip. The order picker again begins at the dock door, starting at 62 meters, picks the last pallet in zone F in the first rack, and heads back to the dock doors. In the end, a total of 101 meters are traveled. When compared to the current storage assignment policy, this policy proves to be more efficient due to its simplicity and decrease in the total distance traveled. For all three trips using the current storage assignment policy, the order picker traveled 163 meters, while he traveled here only 101, saving up 62 meters. This is mostly due to having the pallets close to the dock doors, assigning them in the unused zones of F, G, H, and I instead of having them further away, in the back side of the warehouse.

Order	Client	Distance Traveled
1	PIMZOS	30 meters
2	PIMZOS	34 meters
3	Jeanette	32 meters
4	Mennegat	50 meters
5	Bowiq	54 meters
6	Mr. GPS	38 meters

7	Pentair	101 meters
Total	-	339 meters

Table 5.2 - Distance Traveled for All Orders

To summarize, section 5.3 uses the warehouse sketch and the set of large orders created in section 5.1 to calculate the distance traveled using the new storage assignment policy. The sketches and distances for the rest of the orders can be found in the same Excel file 'Warehouse Sketch - Distances' as the one used to calculate the distance for the current storage assignment policy. Table 5.2 summarizes the findings by showing the distance traveled for each order, and the total distance traveled for all the orders. The next section provides a comparison between the current and new storage assignment policies and summarizes the results.

5.4 Results

This section shows the final results of using the current and new storage assignment policies on the total distance traveled and offers a discussion as to which is more efficient.

Order	Current Storage Distance	New Storage Distance	Difference	Difference (%) per Order
1	50 meters	30 meters	20 meters	40%
2	54 meters	34 meters	20 meters	37.04%
3	44 meters	32 meters	12 meters	27.27%
4	130 meters	50 meters	80 meters	61.54%
5	60 meters	54 meters	6 meters	10%
6	44 meters	38 meters	6 meters	13.64%
7	167 meters	101 meters	66 meters	39.52%
Total	549 meters	339 meters	210 meters	38.25%

Table 5.1 - Total Distance Traveled Comparison

Table 5.1 shows the final results of both storage assignment policies on the total distance traveled. As can be seen in the table, the new storage assignment policy outperforms the current policy in all of the 7 orders. The total distance traveled using the current storage policy is 549 meters, while the distance traveled using the new storage assignment policy is 339 meters. This 210-meter reduction is attributed to storing the fastest moving products in the closest locations, as done with the COI storage policy for single command order picking, and using the OOS storage policy to store the products that are ordered together the most, close together for multi command order picking. Finally, Table 5.1 shows that the new storage locations reduce the total travel distance by 38.25%, which indicates that the new storage assignment policy could potentially perform better than the current one, increasing the order picking efficiency of the warehouse.

In summary, Chapter 5 tests the new storage assignment policy by calculating the distance it takes to pick a set of large orders. After creating a warehouse sketch, and a list of large orders in section 5.1, section 5.2 uses the provided information to calculate the total travel distance using the current storage assignment policy. For all of the seven large orders, the total distance traveled was 549 meters. On the other hand, the total distance traveled using the new storage assignment policy was 339 meters, which is a total decrease of 210 meters. This means that the new storage assignment policy improves the current order picking process by 38.25%. This improvement is mostly attributed to storing the fastest moving products close to the I/O point and having the products that are ordered together the most close together. The next chapter offers conclusions and recommendations that may be insightful as well as worthwhile to carry forward.

6. Conclusion and Recommendations

In this chapter, the conclusion is given in section 6.1 and the recommendations are given in section 6.2.

6.1 Conclusion

After the departure of a big client in the warehouse, many free spaces were created. The warehouse reacted to this change by randomly storing inventory, trying to fill the void of the previous client. As a result, products that were highly compatible with each other were stored far away from each other and products that were fast-moving (ordered a lot) were placed far away from the I/O point. Thus, long travel distances occurred when picking orders, especially in zones A, F, G, H, and I.

EvW wanted a new storage assignment policy for the aforementioned zones to decrease the distance traveled when picking orders by identifying the fast-moving products and storing them closer to the I/O point, and storing products that are frequently ordered together closer to each other. Thus, the main research question of this thesis was:

How can a storage assignment policy improve the order-picking efficiency in EvW's warehouse?

This question was tackled by first researching basic warehouse principles such as the functions of a warehouse and the order-picking process. Then, research was done on storage assignment policies to find the policies that decreased the most travel distance when picking orders. The two storage policies chosen were the Cube per Order Index (COI) and the Order Oriented Slotting (OOS) as they were well-known to decrease travel distances in different order picking scenarios (Schuur, 2015). Moreover, common strategies that reduce the workload of order picking were studied such as the forward-reserve storage strategy which divided a rack into a pick and bulk area.

After gaining more knowledge on the assignment from the literature, the current situation of the warehouse was studied by analyzing the current order picking process and gaining a deeper understanding of the stock stored in zones A, F, G, H, and I in the warehouse. Also, the information required to create and implement the COI and OOS storage policies was extracted from the company by studying the order history from the Warehouse Management System (WMS).

Based on the data found, the COI and OOS storage assignment policies were created and implemented in the warehouse. The new storage assignment policy for zone A combined the COI and OOS storage strategies. However, the new storage assignment policy for zones F, G, H, and I used only a COI policy as the products stored in these zones were only single command orders. When testing the effectiveness of the new storage policies on these zones, the total distance traveled when picking a series of large orders was calculated and compared against the current layout. The result was a 38.25% improvement in the order picking process when using the new storage assignment policies since lower travel distances were realized. This proved that the new storage assignment policies could potentially perform better than the current one.

6.2 Recommendations

The results of this thesis represent a starting point for EvW's journey to increase its warehouse optimization and the efficiency of its order picking process. This section discusses some of the recommendations to carry forward in this research.

A first recommendation would be to increase the scope of the study by including more zones. Due to a switch in the thesis assignment, midway through the journey, the time given was not enough to consider focusing on all of the warehouse, since it would have been too big of a project. Thus, a future recommendation would be to implement the new storage assignment policy in more zones and test it on more products to see if it would also result in positive changes as it did with zones A, F, G, H, and I. Zone B, in particular, is an interesting point of focus since it is also used to store e-commerce products, and it is currently completely occupied by the client, Noordliving. Using both zones A and B to create an efficient order picking layout for all e-commerce clients can be a study in the future.

Another recommendation would be to increase the time frame used when analyzing the order history on the WMS. When analyzing company data for the COI policy, April was taken as a starting point since that was when the big client had left the warehouse. Including more months in the study could produce more accurate findings. In addition, in the topic of time, more products can come into the warehouse in the future, and the demands could always fluctuate. The fast-moving products today can become slow-movers tomorrow, and vice versa. That is why it is important to provide the company with a guideline on how to use the Excel files provided and the codes to adapt to any new situation. In the Excel file: Future Template, a template is given to the company so that they can input any list of locations they want and calculate the COI ratios of any list of products, as long as they input the order amounts and required storage space of these products. They can then be given new locations by using the same codes used in the Excel files: Zone A and Zones F-I, in Modules 3 and 1 respectively.

In addition, when comparing the new and old layouts a return routing policy was used. In the future, other routing policies can be experimented with to see how the results would change. Moreover, the warehouse sketch drawn in Excel was a very simple version of the warehouse. Creating a more complex sketch of the warehouse where it represents more of reality could be an interesting thing to look at in the future. Also, when calculating the distance traveled, multiple assumptions were made such as each white cell representing one meter, all e-commerce products can be picked in one trip, and that the horizontal locations in a rack, A, B, C, and D are all the same distance. These can be changed so that they give more of an accurate calculation of the distance traveled when it is calculated again in the future. For example, instead of each white cell representing one meter, a more accurate metric can be created to calculate the true distance traveled in the warehouse. In addition, a limit can be made to the number of e-commerce products that can be picked up in one trip to make it more realistic. Finally, a distance can be created between the different slot locations A, B, C, and D. These minor changes can give more accurate calculations when measuring the distance traveled in the future.

This research is the starting point for EvW to increase the efficiency of its warehouse. A lot has been done in this thesis with the time given, but it also shows that more can be done in the future. In addition, the proposed storage assignment policies can convince the warehouse workers that a more efficient method of working is possible in terms of their order picking process. Moreover, when implemented, this can safeguard the company's reputation by providing timely/fast services to its customer base. Table 6.1 below shows a roadmap for EvW on what the next steps are to continue working on this project.

	1.5 months	**3 months**	**6 months**	**12 months**
Zones	Add zone B	Test half of the warehouse	Test the whole warehouse	-
Time-frame	In the COI policy, start from January instead of April	For all order history analyses, take 1 year as a time frame	-	-
Assumptions and Limitations	Create distances for different slot locations A, B, C, and D	Create a limit to the number of e-commerce products that can be picked in one trip	-	Create a more complex drawing of the warehouse to calculate the distance traveled more accurately
Implementation	-	Implement the new storage assignment policy in zone B	Implement the new storage policy on half of the warehouse	Implement the new storage assignment policy in the whole warehouse.

Table 6.1 - Roadmap

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Appendices

Appendix A

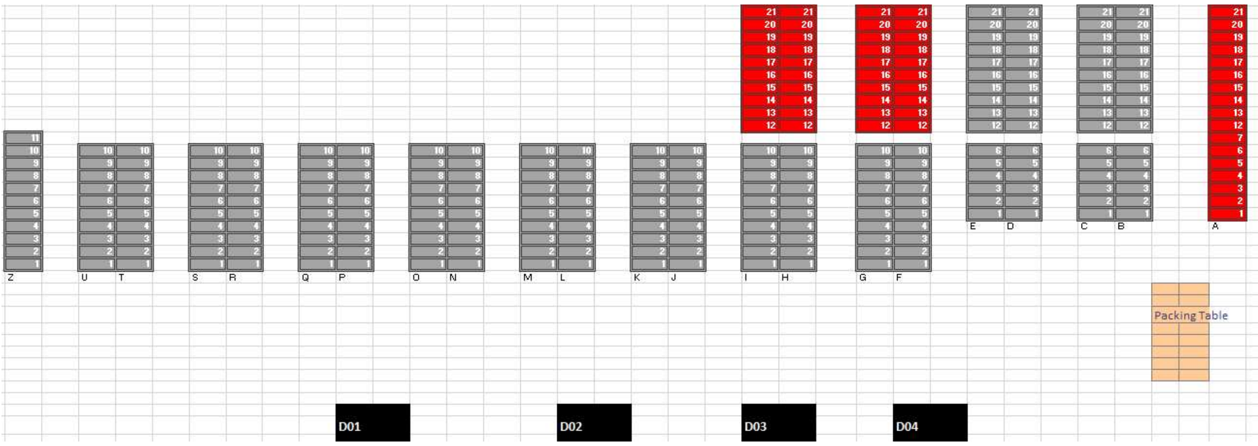

Figure A.1 - Complete Warehouse Sketch

Appendix B

Mennegat's Products	Locations Occupied	Location(s)
SONORA - 6TN (Black)	1	Z02D20
BAS Projector Speaker Industrial	12	Z10D20, Z10B20, Z08B20, Z08D20, Z04A20, Z07A20, Z07D20, Z08A20, Z09B20, Z02A20, Z09A20, Z09D20

Table B.1 - Mennegat Products in Zone Z

Appendix C

	Vitipro	DermaBes	UVB-lichtt	UVB-lichtt	Kernel UVI	UVB-lichttherapielamp Middel snoerloos
Vitipro	x					
DermaBestÂ® Melavitil	7	x				
UVB-lichttherapielamp Klein snoerloo	0	0	x			
UVB-lichttherapielamp klein	0	2	0	x		
Kernel UVB handlamp middel	0	2	0	0	x	
UVB-lichttherapielamp Middel snoerlc	1	3	0	0	0	x

Figure C.1 - Jeanette 6-month interaction frequency

	BoCoustic bas	BoCoustic fini	BoCoustic Plast	BoFiber Eco Light	BoCoustic	BoFiber Eco Light Grey fine
BoCoustic base	x					
BoCoustic finish	3	x				
BoCoustic Plaster	1	1	x			
BoFiber Eco Light Grey	0	0	0	x		
BoCoustic Coat	1	1	0	0	x	
BoFiber Eco Light Grey fine	0	0	0	0	0	x

Figure C.2 - Bowiq 6-month interaction frequency

	IP POWER	ACRO DIN-Rail \	LabJack U	Power Cor	Apparaats	PFH16240	IP POWER	Sensor Ca	IP POWER	PT100 Out	LabJack U	EX9520R	MS1
IP POWER 9255GE	x												
ACRO DIN-Rail Voeding AD1048-24FS (24VDC/2A)	0	x											
LabJack U6	0	0	x										
Power Cord Schuko 1,8 meter - VDE - Schuko to C13 - Black	11	0	0	x									
Apparaatsnoer FWL Schuko Haaks, 1,8 meter, 3 x 0,	0	3	0	0	x								
PFH16240	0	0	0	0	0	x							
IP POWER 9850GE	0	0	0	0	0	0	x						
Sensor Cable M8, 4-pole, Radial, 5 meter PVC	0	0	0	0	0	0	0	x					
IP POWER 9258S+PING	0	0	0	2	0	0	0	0	x				
PT100 Outdoor Sensor, Class A, 3-wire	0	0	0	0	0	0	0	0	0	x			
LabJack U3-HV	1	0	0	0	0	0	0	0	0	0	x		
EX9520R	0	0	0	0	0	0	0	0	0	0	0	x	
MS1	0	0	0	0	0	0	0	0	0	0	0	0	x

Figure C.3 - PIMZOS 6-month interaction frequency

	mrgps-draagtas	Zumo-xt2
mrgps-draagtas	x	
Zumo-xt2	13	x

Figure C.4 - Mr. GPS 6-month interaction frequency

	AtlasIED A-	AtlasIED AZ	AtlasIED AZ	AtlasIED C-	AtlasIED C-	AtlasIED FS	AtlasIED W	AtlasIED X-	AtlasIED X-	BAS DigiBe	Centolight
AtlasIED A-BT-EU	x										
AtlasIED AZM4	3	x									
AtlasIED AZM8	1	3	x								
AtlasIED C-V-EU	0	0	0	x							
AtlasIED C-ZSV-EU	2	2	2	0	x						
AtlasIED FS12T-99	0	0	0	0	0	x					
AtlasIED WTSD-MIX31K	1	5	2	0	1	0	x				
AtlasIED X-ANS-EU	0	3	4	0	1	0	1	x			
AtlasIED X-ZPS paging mic	1	2	0	0	0	0	1	0	x		
BAS DigiBell - Schoolbel en Pa	0	1	0	0	0	0	0	0	0	x	
Centolight Clubwasher 360	0	0	0	0	0	0	0	0	0	0	x
Centolight Lightblaster 200	0	0	0	0	0	0	0	0	0	0	0
Centolight MOOD 1818WP, outdoor IP65, 18x18W RGBWA	0	1	0	0	0	0	1	0	0	0	0
Centolight Moodliner 1430WP	0	0	0	0	0	0	0	0	0	0	0

Figure C.5 - Mennegat 6-month interaction frequency

0	0	0	0	0
0	1	1	0	0
0	0	1	0	0
0	0	0	0	0
1	10	2	0	0
0	0	0	0	0
0	1	0	0	0
0	0	0	0	0
0	0	0	0	0

Figure C.6 - Mennegat 6-month interaction frequency (2)

	Children's dinner set Miffy, 6 pieces	Zendingen Mercis
Children's dinner set Miffy, 6 pieces	x	
Zendingen Mercis	0	x

Figure C.7 - Mercis 6-month interaction frequency

Appendix D

Color	Client
Red	Jeanette
Blue	PIMZOS
Yellow	Mennegat
Green	Mr. GPS

Table D.1 - Legend for OOS Storage Assignment Policy