UNIVERSITY OF TWENTE.

Bachelor thesis
Faculty of behavioural, management and social sciences

Organising a fulfilment warehouse with fluctuating inventory

First supervisor
Dr. M. Koot

Second supervisor
Dr. P. Schuur

Author
Keano Oliver Collins

Year 2024

Preface

Dear reader,

This document presents my bachelor thesis, which I have written to conclude my Bachelor of Industrial Engineering and Management at the University of Twente. During the past half year I have conducted the research at company X. The goal of the research was to help the company move from their smaller warehouse to a much larger warehouse. At the time of writing this the company is transitioning towards the new warehouse, using the results from the research. I am very happy that the research helped me earn my conclude my bachelor of Industrial Engineering and Management, as well as directly help the company move to the new warehouse.

I would like to thank the two managers of company X, both of you helped me tremendously during the span of the research. During the past half year I felt like an integral member of the company. This lead to feeling very motivated during the research as well as enjoying the process.

Secondly, I would like to thank my University of Twente supervisors Dr. Martijn Koot and Dr. Peter Schuur for their help, feedback and support during the period of performing the research. During the feedback sessions I always felt supported and acknowledged, this helped me a lot and is greatly appreciated.

Thank you.

Keano Collins
August 28, 2024

Glossary

Greenfield A warehouse is built according to preferred specifications [2].

Brownfield A warehouse building is already in place, but the layout still needs to be determined [2].

Fulfilment centres Fulfilment centres are warehouses that are designed to manage single-item orders.

Order fulfilment Order fulfilment is the complete logistic process of receiving, processing and shipping products.

Order picking Order picking is a process in warehouses to retrieve products from their storage space.

Bulk storage Bulk storage is storage that is used for large quantities of a product. These products are often stored in big boxes and do not need to be accessed often.

WMS WMS is a abbreviation of "Warehouse management system", a WMS stores information regarding the quantities, locations etc.

Picklist The WMS uses picklists to show products that have to be picked.

Storage method Storage methods indicate the way that products are stored in the warehouse.

Replenishing Replenishing is the process of placing products (from bulk) in their storage location.

Retrieval Retrieval of products is the process of getting products out of their storage spaces.

Stackability In this paper stackability is to what extent a product can be stacked. There will be three possible scores for stackability; A,B and C. These score can be assigned by observing the product and predicting how well the product would stack. The "A" is assigned when a product is very well stackble. A score of "B" is assigned when a product can be stacked but requires support. A score of "C" is assigned when a product can hardly be stacked, even with support.

Shape flat A product is considered flat when the height of the product is significantly smaller than the length and the width.

Shape tall A products is considered to have a tall shape when the height is larger than the length or the width. Tall is not used when it exceeds a certain height, it is used to describe the shape of a product.

Shape regular When a product is not considered as flat or tall it is considered as regular shaped.

Summary

The goal of this research is to organise a fulfilment warehouse with fluctuating inventory. The research is performed for fulfilment company X. The company is moving towards a larger warehouse which gives the company the opportunity to reorganise the warehouse to improve the organisation and efficiency.

Motivation The inventory of company X is constantly fluctuating as it depends on what is provided by their customers. The fluctuation is about the types of products that are in the warehouse. Two problems that are experienced in the warehouse are: inefficient use of available space; and products that are hard to retrieve. The empty space in the warehouse is not desired as this costs the company money. For products that are hard to retrieve finding the right product is difficult and time consuming. This wastes a lot of time as the retrieval of products happens multiple times a day. To solve these problems alternative storage methods are selected and implemented. The storage methods cannot directly be selected as another problem that company X is facing is a knowledge problem. The knowledge that is missing is, is knowledge regarding the inventory of company X. The managers and employees know what products are in the warehouse, but a general overview of all products together with the product characteristics is missing. This knowledge is required to make informed decisions regarding the organisation of the new warehouse.

Research question To solve the previously mentioned problems the research question has to be answered. The research question is:

How to organise a fulfilment warehouse by implementing new storage methods?

Answering the research question is done by solving the two problems mentioned previously. The problems are solved by acquiring suitable storage methods as well as assigning products to the appropriate storage method. Suitable storage methods will solve the organisational problem as different products are not stored in the same space anymore. The second problem is solved by again, using more suitable methods as well as selecting the right storage method for the products.

Methodology The research consists of three main parts. The first part is about researching the topic of my research. This is done by first using literature to gather a broader understanding of the different topics that are a part of my research. This includes fulfilment warehousing and storage methods in these types of warehouses. This part of the research is required to gain a better understanding of the topic as well as selecting possible solutions to answer the research question. Secondly, I need to gain a better understanding of the processes of company X. I will create two business process modelling (BPM) models: one about product shipping and; one about product entry. Investigating both these processes closely will lead to a better understanding of the company.

The second part of the research is the classification framework which is the part of the research that helps the company gather information to answer the knowledge problem. In the first part of this section the appropriate attributes for the products in the warehouse are selected. After selecting the appropriate attributes a dataset is created that contains attributes of the products in the warehouse. The second part of this section will connect products to the appropriate storage methods based on the attributes of the products. This step is necessary as the clustering is performed using a data set of the inventory, however connecting products to the storage method should also be performed for products that are not in the data set. Rules are determined

to connect a product to a storage method based on the attributes of the product. These rules are based on the data found in the dataset as well as the characteristics of the selected storage methods.

Results It has been found that new storage methods increase the storage capacity per square meter. It is found that using alternative storage methods decrease the required storage racks by 49% (20 racks versus 39). The capacity increases because the new storage methods use the available space more efficiently than the current shelf racks. This means that less storage methods are required to store the same amount of products. Additionally, the retrieval time of product will decrease due to better organisational capabilities of the new storage methods. Different products are not stored in the same storage space anymore, making it easier and quicker to find the right product.

Recommendations Recommendations for the company consist of two parts; storage methods and components of the warehouse. The three storage methods to use in the new warehouse are pallets, shelf racks and the new custom closets. The quantities of storage methods depends on what is valued most by the company, therefore three possible solutions are described; minimal, economical and organisational. These solutions are different perspectives on how to solve the problem. The minimal solution focusses on keeping costs down. The economical solution focusses on solving the problem while still keeping costs down. Lastly, the organisational solution prioritises solving the problem, with a focus on meeting all requirements. The decision is made to provide three different perspectives in order to help company X solve the problem how they see fit. For the components of the warehouse, it will be beneficial to use order picking carts to decrease to walking distance of the order pickers. Another recommendation is to allocate a dedicated space to create a fast-pick area for the fastest moving products.

Contents

1 Introduction

This chapter introduces the research project and the problem that company X is facing. The chapter starts with introducing the situation at company X. After this the problem is explained together with the problem solving approach. Lastly, the research question is divided into research questions to solve the problem in smaller parts.

1.1 Current situation

Company X is a fulfilment company which specialises in personal service for its customers. Fulfilment companies have customers that sell their products using their own web shop or online marketplaces. These customers do not have their own warehouse which is why they are customers of company X. Company X takes care of the activities regarding the logistics of selling a product. The clients of company X sell products and pay company X to handle the logistic activities. Products of their customers are stored, picked, packed and shipped by company X.

The company earns its money by charging fees for storing, packing and shipping products. There are two different types of clients, fulfilment clients and drop-ship clients. The fulfilment clients store their products in the warehouse of company X. Drop-ship clients do not store their products in the warehouse of company X, received packages are shipped on the same day. Fulfilment clients are the desired clients as these clients are also charged for storing their products.

There are three types of employees working at company X. Firstly, the two co-managers and founders of the company handle the big picture activities in the company. Together, the two of them make the decisions about customer acquisition, marketing, investments etc. The company started with just the two of them, but as they grew they took on more personnel. The first type of employee at company X is the order picker and packer. The picker/packers will now be referred to as pickers, in line with the company's terminology. The task of the order picker is to make sure all products are ready to be shipped at the end of the day. The process of preparing a product for shipment starts by picking the product from its respective storage space and bringing the product to the packaging table. At the packing table the appropriate packaging type is selected after which the product is packaged and stored on a roll container or pallet. The last activity is assisting the delivery service employees who pick up the roll containers or pallets.

The last type of employee is the trainee which sits between the co-manager role and the picker/packer role. The trainees have more responsibilities such as opening and closing the building and helping customers solve their problems. They also perform the picking and packing tasks if not enough pickers are available.

Company X is a manual order picking warehouse where every activity is performed by human employees. The order pickers are the employees who perform the daily activities in the warehouse. The picker collects the product from the warehouse using the WMS, then the storage material is selected and then the product is packaged. The process is shown in figure 1. A larger image can be found in appendix A.

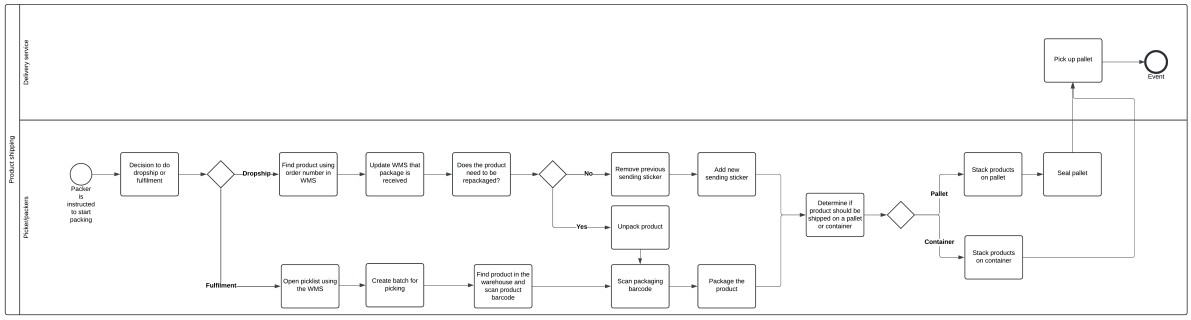

Fig. 1: Product shipping BPM

1.2 Problem description

Company X has outgrown their current warehouse which is why company X is moving towards a larger warehouse. To arrange the new warehouse the types and quantities of desired storage methods are required. These aspects are important as the two main problems (organisation and inefficient use of space) can both be solved by selecting the right types of storage methods and the corresponding quantities. This information is difficult to determine as there is no structured overview of the inventory of the warehouse. This information has to be acquired before moving to the new warehouse.

The problem is a knowledge problem as the company requires information which they do not possess. The problem is not noticeable during the daily operations of the company. The company expects that as the company grows, problems will become more prominent which is why the problem needs to be addressed. The problem is solved when the company has enough information to make informed decisions about the types of storage and the corresponding quantities. The information that is missing is information about the characteristics of the products in the warehouse. This information will serve as a basis to select the appropriate storage methods.

1.3 Research questions

The goal of the research can be summarised in one research question to which the answer is the conclusion of my research. The research question is:

How to efficiently organise a fulfilment warehouse by implementing new storage methods?

This research question cannot directly be solved as this question requires additional information before it can be answered. To answer the research question there are research questions for every chapter.

Theoretical framework The storage methods are discovered in the theoretical framework. The section discusses what storage methods can or will be used in the new warehouse for company X. The research

questions are:

- What are different storage options for products in a fulfilment warehouse?

  This answer will be based on results found through literature. The options to look for are possible storage options that can be used in a fulfilment warehouse. The answers to this research question will not directly be used in the new warehouse. The overview will be created first in order to make the best selection of storage methods.

- What are different storage methods suitable for company X?

  Answering this question will lead to selected storage methods that can be suitable for company X. The decisions will be based on the advantages and disadvantages identified in the selection of possible methods. Additionally the decisions will be made together with the managers of company X. They know what storage methods are required in their warehouse, by providing the possibilities they can make informed decisions regarding what methods to use.

- How can a warehouse be organised using warehouse storage systems?

  Another way of managing storage in a warehouse is through warehouse storage systems. These systems do not focus on individual storage spaces but more on organising the warehouse as a whole. The question will be answered by providing possible systems for organising a warehouse. The possible systems will be found using literature and select systems that can be implemented in a fulfilment warehouse.

Components of the warehouse The components of the warehouse explained in section 3 will cover the activities in the warehouse and the equipment required to perform these activities. The questions that will be answered in this section are:

- What activities are performed daily at company X?

  This question will be answered by observing the activities in the company as well as performing interviews with the employees working at company X. The questions I will ask will be questions such as:

  - "What activity are you performing now?"
  - "Why are you performing this activity?"
  - "Is this a daily activity?"

  These questions can be used, however there is a lot of interaction between employees at the company so most of the questions will be asked in an informal conversation.
  Gaining a better understanding of the company is crucial for recommending solutions as I need to be able to judge if a solution will be beneficial.

- What are time wasters happening currently?

  This research question will be answered by conducting interviews with the managers of the company. My goal is to provide recommendations to organise a (fulfilment) warehouse. The recommendations

should also focus on creating an efficient warehouse which eliminates possible time wasters. The managers are the employees that have the best overview of what time is wasted and how this can be improved.

- What equipment is required for performing these activities?

  The first step of answering this question is observing the equipment that is used in the current warehouse of company X. After making a list of the equipment observed I will discuss with the managers which equipment is required and what equipment needs to be used in the new warehouse. During this conversation I will also ask what equipment is missing in the current warehouse or what needs to be acquired in the new (larger) warehouse. These items will then be added to the list of equipment that is required. This interview will also directly answer the last research question.

- What equipment should be acquired when moving to the new warehouse?

Classification framework The classification framework explained in section 1.4 will create an approach to determine the category and storage method for every product in the warehouse. The research questions that will be answered are:

- What attributes can be used for products in a (fulfilment) warehouse to differentiate products?

  Three different methods will be used to find possible attributes; literature search, observation and a panel meeting. In this first part of the classification framework the goal is to find as many attributes as possible that might be useful for the eventual framework. Most attributes will not be used, however by gathering many different attributes the best selection can be made. The first method will be literature search as this method will be useful for determining many attributes that have been used previously or can be used in a warehouse. Secondly, observation will be used to find attributes that are more specialised for company X. Literature search will provide general attributes while I can find specialised attributes through observation. Lastly, a panel meeting will be held with the two co-managers of the company. During this panel meeting I will explain the purpose of the meeting together with the attributes already collected. As they have more expertise than me regarding the topic they can provide additional attributes which I might have missed or are very company specific.

- What attributes are used for categorising the products?
  A selection of attributes has to be made to create the classification framework. To create this selection a number of attributes need to be dropped. Attributes will be dropped if they are not relevant for classifying products.

- How to connect attributes of a product to a suitable storage method?

  The end goal of the classification framework is to answer this last research question. The attributes that will be collected will be used to determine different categories for the products. The categories of the products will then be used to connect a product to a storage method. The solution will be data driven using the inventory in the warehouse.

1.4 Problem solving approach

The research begins with a theoretical framework regarding fulfilment warehousing. In this section different storage methods for fulfilment warehouses are discussed. This is followed by researching the components of the warehouse. The goal of this part is to gain a better understanding of the equipment in the warehouse as well as gaining an overview of the processes that have to be performed. After this the classification framework is created. The classification framework consists of two parts. The first part is about determining what storage methods to use based on the current inventory. The second part will be about categorising products based on its attributes and provide a recommendation for which storage method to use. These sections will lead to a better understanding of what the warehouse has and what needs to be acquired for moving towards the new warehouse.

Theoretical framework The research starts with a theoretical framework about fulfilment warehouses. This section discusses general information about warehousing and storage. The section starts by discussing fulfilment warehousing and the similarities and differences between general warehousing and fulfilment warehousing. The next part of the section covers manual warehousing, as company X is a manual warehouse. Lastly, an overview is provided of storage methods that can be used in fulfilment warehouses. The storage methods are explained and advantages and disadvantages are discussed.

Components of the warehouse This section discusses the components of the warehouse. This section starts by covering the activities in the warehouse as well as all the equipment that is currently used to operate the warehouse. Next, the section explains the activities that have to be performed daily. Creating an overview of all the methods will help me gain a good understanding of how the warehouse functions and what is required to perform the activities.

After this the warehouse equipment is researched. This subsection dives in to what equipment the company already owns and what needs to be acquired in the new warehouse. After this, the inventory of the company is investigated regarding storage methods in the warehouse. This information is required to make the right recommendation for the quantity to acquire in the new warehouse.

Classification framework The classification framework has two different parts; the selection of storage methods and the classification of the products.

Before the storage methods can be selected an overview of the different products in the warehouse is created. This part starts with gathering attributes to describe and differentiate products that are stored in the warehouse. The process starts with gathering possible attribute, after this a number of attributes are selected based on relevance for the research and the situation at company X. To solve the knowledge problem a dataset will be created of the different products in the warehouse with its corresponding attributes. The products will be clustered using the attributes which leads to sub groups in the data set. The storage methods will be based on the characteristics of the sub groups.

The next part will connect products to corresponding storage methods. This step is essential as the inventory of company X is constantly changing. A new product that enters the warehouse has to be assigned to the appropriate storage method based on the characteristics of the product. Assigning of a product will be performed using a decision tree which connects the product to the storage method. This decision tree will

be made using a script such that connecting a products to a storage method can be performed consistently.

This section solves the knowledge problem of what storage methods to acquire. The framework then acts as a decision tree to determine the storage methods for new and current products.

Recommendations The recommendations will solve the core problem by providing recommendations on what storage methods to acquire, the quantities and recommendations for the warehouse itself. The recommendations cover both the types of storage methods as well as the quantities of specific storage methods. The recommendations will help the company in moving to the new warehouse and creating an efficient warehouse.

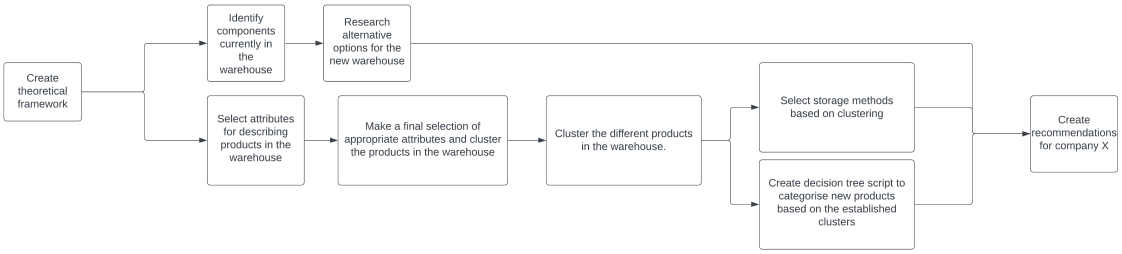

Fig. 2: Problem solving approach

1.5 Methodology

This section covers the research methodology used to perform the research. The section covers the research design, research methods, data collection, data analysis and the limitations of the research.

1.5.1 Research design

The research consists of multiple steps to solve the problem for company X. A mixed-methods approach is used to perform the different types of research. The first step of the research is to perform exploratory research to gather information about (fulfilment) warehousing. This part of the research is essential as this will provide me with the knowledge required to understand and solve the problem.

The next part of the research is exploratory research to explore attributes that can be used for describing products in a warehouse. This step is preparation for the data gathering as establishing what information to gather has to be performed first. When the possible attributes are found the appropriate attributes will be selected based on what is suitable for the products in the warehouse of company X.

After the attributes are selected, descriptive research will be performed to gain a better understanding of the inventory in the warehouse. This part of the research will be performed manually as the desired information

is not stored in the WMS.

After the dataset has been created, analytical research will be performed to gain an understanding about the inventory of the warehouse. The goal of this part of the research is to create groups/clusters based on the attributes of the different products. This step is important for inspecting the dataset as well as connecting products to their appropriate storage methods.

1.5.2 Research methods

Multiple different research methods will be used, this section explains the methods that are used during the different parts of the research.

The first step of the research is to perform exploratory research using literature search as the research method. Literature is a good method to start, as it enables the researcher to quickly gain an understanding about the topic of the research.

The second step is to perform exploratory research to find possible attributes for the products in the warehouse. Three different research methods have been used; literature, observation and a panel meeting. Literature search was performed to find attributes that have been used by other researchers. The second method to use is observation in the warehouse. This method is chosen to find attributes that are relevant for products in the warehouse of company X. The last method that is used is performing a panel meeting with the two managers at company X. The panel meeting starts with sharing attributes that have already been found and explaining what the different attributes are. Now that it is clear what attributes should be the question will be asked what methods are missing. The previous two methods will identify attributes, but the expert opinions of the managers can help identify more (useful) attributes.

1.5.3 Data collection

The data collection is an important part of the research as the required data for my research is missing. The desired dataset has to contain attributes that have been selected during the exploratory research performed earlier. The dataset has to be a file with columns containing the attributes of a product. The data is gathered using a created google forms to store the results in a data file. During the data collection process a ruler and scale have to be used to gather the attributes of different products. Additionally, the WMS has to be used to gather information about products that is stored in the WMS.

1.5.4 Data analysis

The previously gathered data sheet is used to perform data analysis on the inventory of the warehouse. The previously mentioned goal of the research is to create clusters such that products can be grouped together based on their attributes. The analysis will be performed using data mining program Orange. Orange has a function called "hierarchical clustering" which clusters data based on different kinds of attributes. After the clusters are created the clusters are analysed to determine the characteristics of the clusters. Based on the characteristics of the clusters storage methods are selected.

1.5.5 Limitations

The quality of the clustering depends on the number of clusters as more clusters leads to clusters that have more similarities. There is a trade-off to be made as there is a maximum number of different storage methods that can be implemented in the warehouse. The right number of clusters is unknown and is difficult to determine. This means that the question remains whether the solution will be optimal.

2 Theoretical framework

This section discusses topics that are important for my research: fulfilment warehousing; and storage methods. The section starts with general information about warehousing and storage to gain an understanding for the situation at company X. Company X is a fulfilment warehouse which is a specific kind of warehouse. The characteristics of a fulfilment warehouse are discussed in this section. Lastly, this section provides an overview of storage methods that can be used in a warehouse. This overview contains advantages and disadvantages of the products.

2.1 Warehousing

To gain a better understanding of warehousing, the book "Warehouse management" by Brynne Richards [9] is used to gather information. According to the "Cambridge dictionary" the definition of a warehouse is: "a large building for storing things before they are sold, used or sent out to shops". For company X the purpose of the warehouse is to store products before they are sold and sent out to customers. The warehouse is considered to be a traditional warehouse as no smart technologies are used. In the paper by Kamali [6] traditional warehouses are compared to smart warehouses. The paper mentions that more and more companies are transitioning into smart warehouses mainly because efficiency increases and machines can work 24 hours per day.

Company X does not have a traditional warehouse, but a fulfilment warehouse. In the book by Gwynne Richards [9] fulfilment centres are warehouses that are designed to manage single-item orders. The type of fulfilment that company X performs is dedicated fulfilment. Dedicated fulfilment is fulfilment performed in a warehouse that is owned by a single company. The alternative is multi-client fulfilment, this is the case when the warehouse is owned by multiple clients who share the space in the warehouse. Challenges about fulfilment mentioned by Richards are fluctuating inventory, wide-range of products and strict delivery rules.

As there are many different clients who sell different products the inventory is constantly changing. The inventory can change per season or per week which the warehouse should be able to handle. Another similar problem is that the products can vary significantly, this means that one type of storage method will not be enough to store all the products in the warehouse. Lastly, the warehouse has to perform its tasks efficiently as the delivery rules can be very strict.

For writing this section lecture slides by Dr. Peter Schuur (Schuur, P. (n.d.). Warehousing: Some basic ideas [Slide show].) were used.

2.2 Storage methods

There are many different storage methods that can be used in a warehouse. The storage methods should be able to store a wide variety of products. Richards [9] mentions a number of different options for storage methods in a warehouse. The options that are suitable for a fulfilment warehouse will now be discussed.

2.2.1 Pallet storage methods

- Block stacking

  Block stacking is a cheap way to store pallets in a warehouse. Next to the pallets, no additional equipment is required. The pallets are used as "blocks" and are stacked on top of each other to utilise vertical space in a warehouse. This method is not the most stable and can only be used for pallet products that can easily be stacked.

Fig. 3: Block stacking at company X

- Wide aisle pallet racking
  This racking is used in the majority of warehouses worldwide. The method is very versatile without the need to specialised equipment. Access to the pallets is quick and easy compared to other forms of racking. The disadvantage of this method is that wide aisles are required to allow the machines to make turns.

- Double-deep racking

  Double-deep racking is similar to the wide aisle pallet racking method. The key difference is that as the name suggests pallets can be stored two pallets deep instead of one. The advantage is that this method is very space efficient as less aisles are required. The disadvantage is the access speed is slower and specialised equipment is required to store the pallets.

Fig. 4: Double-deep racking

- Narrow aisle racking

  This method increases storage capacity by having narrow aisles to create additional storage space. The method is space efficient, but specialised material is required.

Fig. 5: Narrow aisle racking

- Drive-through

  This method takes double deep racking even further as more than two pallets can be stored behind each other. The machines can drive into a lane to retrieve the pallet from storage. The advantage is that there is no need for aisles as the pallets are stored in the aisles. The disadvantage is that not every pallet can directly be accessed which means that this method is suitable for large quantities of individual products.

Fig. 6: Drive-through racking

- Mobile racking

  Mobile racking places the pallet racks on movable rollers such that aisles can be created when required. This method is very space efficient as only one aisle is required. This aisle can then be created when a pallet needs to be retrieved. This method is space efficient but has a lower retrieval speed. This method shall be considered when the floor space is expensive.

Fig. 7: Mobile racking

- Stacking frames

  Stacking frames are similar to the previously discussed racking systems. The key difference is that the previous discussed racking systems only have beams to support the pallets. Stacking frames do not have beams but entire platforms. The advantage of having entire platforms is that different sized products can be stored, while pallet racks can only store pallets. Use stacking frames makes the warehouse more versatile as other bulk products can also be stored using these frames.

Fig. 8: Stacking frames

Drive-through racking is an example of deep lane racking. There are more types of deep lane racking, the decision was made to not discuss these methods. The reason is that deep lane storage racks are used for large amounts of pallets with the same products. This situation is not applicable in the warehouse of company X, therefore these methods are not discussed.

2.2.2 Individual product storage methods

For the picking of products it makes sense to use smaller storage spaces to store the individual products. For large products the previously mentioned methods can be used, now methods will be discussed that are suitable for smaller products.

- Shelf racks

  Shelf racks are very similar to stacking frames but are smaller sized. These racks have different levels and are used to store and pick individual products. Shelving racks can be customised by altering the length, width and height to create the best shelving rack for the storage needs. The shelving racks can be used by itself, but for smaller parts additions can be made. A method that is often used are bins to store smaller products and keep them separated. Another method is using dividers on the storage shelf. Dividers are physical walls placed on a shelf to separate different products that are positioned on the same shelf.

Fig. 9: Shelf racks

- Flow rack

  Flow racks are shelf racks with tilted shelves. The idea is that products are replenished at the back of the shelf. When a product is retrieved from storage, the next product slides forward. This has the advantage that the products are always positioned closets to the order picker. This method is especially appropriate for fast moving products as the replenishing and retrieving can easily be performed. The back of the rack is always easily accessible. The retrieving is fast because the products can easily be reached.

Fig. 10: Flow rack

- Custom closets
  A storage method that the company informed me about are custom closets. These closets are similar to shelf racks, but the shelves are adaptable. The closets have shelves and walls which create compartments in the closets. Adaptable means that shelves/walls can be removed or added. This leads to compartments that are able to take different sizes depending on the product that has to be stored. This adaptability is highly valued by the company, which is why this method was presented to me.

- Automated storage and retrieval systems

  In smart warehouses the storing and retrieval of products can be automated. These systems are used to create a warehouse that can operate continuously. Another advantage of this system is that less employees are required to fulfil the daily tasks at the company. The automated systems are difficult and expensive to implement in a warehouse.

Fig. 11: Automated storage and retrieval systems

2.2.3 Warehouse organisation

Warehouse organisation is organising the warehouse as a whole. Warehouse organisation is about storing a larger part of a warehouse to increase storage space. There are two methods that will be discussed about warehouse organisation that will be discussed in this section. The two methods are multi-tier shelving and mezzanine flooring.

- Multi-tier shelving

  Multi-tier shelving is a warehouse organisation method that adds additional floors to pallet racks. The idea is that more vertical space can be used for picking of products. This method works well as more warehouse space can be use which will increase storage space. The problem with this method is that navigating between the different floors takes time.

  The image was obtained from AR racking. (2024). *Multi-tier shelving*[Image]. https://www.ar-racking.com/en/storage-systems/industrial-racking-systems/shelving/multitier/

Fig. 12: Multi-tier shelving

- Mezzanine flooring

  Mezzanine flooring is an additional floor that is placed between the ground and the roof of a warehouse. The idea is similar to the idea of multi-tier shelving, additional walking space in the warehouse to increase storage capacity. A mezzanine floor can be placed where not all vertical space in a warehouse is used. Pallet racks can be stored as high as desired, however using mezzanine flooring creates additional walking space which increases places where products can be picked. The advantage of a mezzanine floor compared to multi-tier shelving is that the additional space can easier be accessed as it is one big platform. The platform can be accessed through stairs instead of small lifts which makes the process quicker and easier.

  The image was obtained from IQS Directory. (2024). *Mezzanine floor*[Image]. https://www.iqsdirectory.com/articles/mezzanine/mezzanine-floor.html

Fig. 13: Mezzanine flooring

2.3 Data analysis

For the data analysis the tool Orange is used to perform the analysis. The main function that is used is called the hierarchical clustering, this tool is used to create clusters of the products that are in the

warehouse. Products are clustered based on the Euclidean distance between the products. In general the Euclidean distance is calculated by using the following formula:

$$d(p,q) = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + ... + (p_n - q_n)^2} \tag{1}$$

The problem with using this formula is that my products also contain the stackability score, which is a non-numerical value. To solve this issue Orange has the "continuize" widget, this widget transforms non-numerical values into continuous values. By doing this formula 1 can be used to compute the distances. The hierarchical clustering widget can be used to change the desired number of clusters.

2.4 Summary

To summarise this chapter the research question mentioned in section 1.3 are answered. The first two research questions will be answered first, the first two questions are:

- What are the different storage options for products in a fulfilment warehouse?
- What are different storage methods suitable for company X?

The storage methods can be divided into two parts; pallet storage methods and individual product storage methods. The pallet storage methods can be found in subsection 2.2.1. A key reason for dropping methods is that some methods are used for storing multiple units of a single product. For example the previously mentioned drive-through racking is not suitable for company X as not every pallet can directly be accessed. The two methods to choose between are wide aisle pallet racking and stacking frames. These two methods are very accessible which is why these are selected. As company X does not need to store any different sized products the decision is made to go for pallet racks.

For individual products there are three methods discussed in subsection 2.2.2. The flow rack is not selected as the main use case for the flow racks are large numbers of similar products. As company X has many different products implementing this method would be difficult. Additionally, the efficiency of this method is questionable as the use case is different, compared to observed use cases of the flow rack.

The shelf racks and custom closets are implemented as these methods are efficient, versatile and easy to implement. The custom closets are implemented as these provide organisational structure which is necessary for company X. Additionally, these closets can have many different sizes which makes them very versatile which is desired. The shelf racks are a basic but efficient solution for the easy to store products in the warehouse. The racks provide a lot of space and can be placed on the floor below the pallet racks.

The last question to answer is:

- How can a warehouse be organised using warehouse storage systems?

Subsection 2.2.3 discusses two methods that can be used to increase floor space in a warehouse. Both methods can be used to increase the floor space in warehouses. The decision is made to not implement these methods as increasing the floor space in the warehouse is not required for company X. Implementing these methods is expensive, when a warehouse reaches its capacity it can be economically viable to implement one of the two methods, but for company X this is not the case. That is why it is decided to not implement either of the two methods.

3 Components of the warehouse

This section will cover all components of the warehouse which are required to have a functioning warehouse. The section covers the components of a warehouse that are required in the new warehouse, the recommendations are based on what the company already owns and what still needs to be acquired before moving to the new warehouse. As the storage methods have been covered already, this section will dive into the components that are required to operate a warehouse. This section starts by discussing the activities in the warehouse which will give a better overview of everything that is required in the warehouse. After this, the equipment to perform these activities is discussed. Following this part is an investigation of what the company already owns and can be used in the new warehouse.

3.1 Activities in the warehouse

In order to function there are certain tasks that need to be performed in the warehouse. The different tasks in the warehouse will be discussed in chronological order.

Product entry The customers of company X deliver their goods at the company which leads to multiple deliveries a day. The product entry is about placing the products in their respective storage spaces using the WMS. When the product has already been in the warehouse the WMS will return the previously used location such that the product can be stored there. When a product that has never entered the warehouse before enters the warehouse a new location has to be assigned to the product. This decision is based on where other products from a client are stored, a decision has to be made whether this approach will be used in the new warehouse. In the future this decision can also be made using the framework explained in section 4. Using the framework has two advantages: the first advantage is that it is quick, the employee does not need to think about the decision; and the second advantage is that the framework is unambiguous, it does not matter which employee performs the result will be be consistent.

Order picking When an order is placed the products for the order need to be picked in the warehouse. This process is performed using the WMS which shows the user exactly what to pick. The WMS is used to store quantities of products, product codes and locations, this information is used for the daily operations but does not help when investigating the inventory. Currently, the order picking is performed using batches which leads to faster order picking. The batches are created by filtering per client. The idea is that similar products are picked in one batch, which leads to more repetitive picking, which increases speed during the picking process. To research this process I tried it out myself and found that the process is not efficient as only one product could be picked per run. The products had to be picked and packed, after the packing a new product has to be picked even though they are stored close together. To solve this an order picking cart can be used to pick multiple products in one go.

Order packing As mentioned previously the orders are packed on the packing table in the warehouse. The packaging can be performed efficiently as the packing materials are stored next to the packing table. During the packing the correct packaging materials has to be scanned, the product is packed and then the product is ready to be shipped.

Container/pallet building Now that the individual products have been packed the products can be shipped towards the customer using the delivery services. The collecting of products is done using either pallets or containers. The products enter the warehouse when they are either: delivered using a delivery service; or the clients deliver the products directly. The products and boxes are mostly stored in containers because they can be easily transported throughout the warehouse. The order pickers are responsible for building pallets such that the delivery services can easily pick up the products. This activity can be performed quicker when packers have enough space to move around freely.

Two BPM models of the activities have been created. Larger images can be found in appendix A. These BPM models show the actors who perform the activities in the warehouse and how the actors interact.

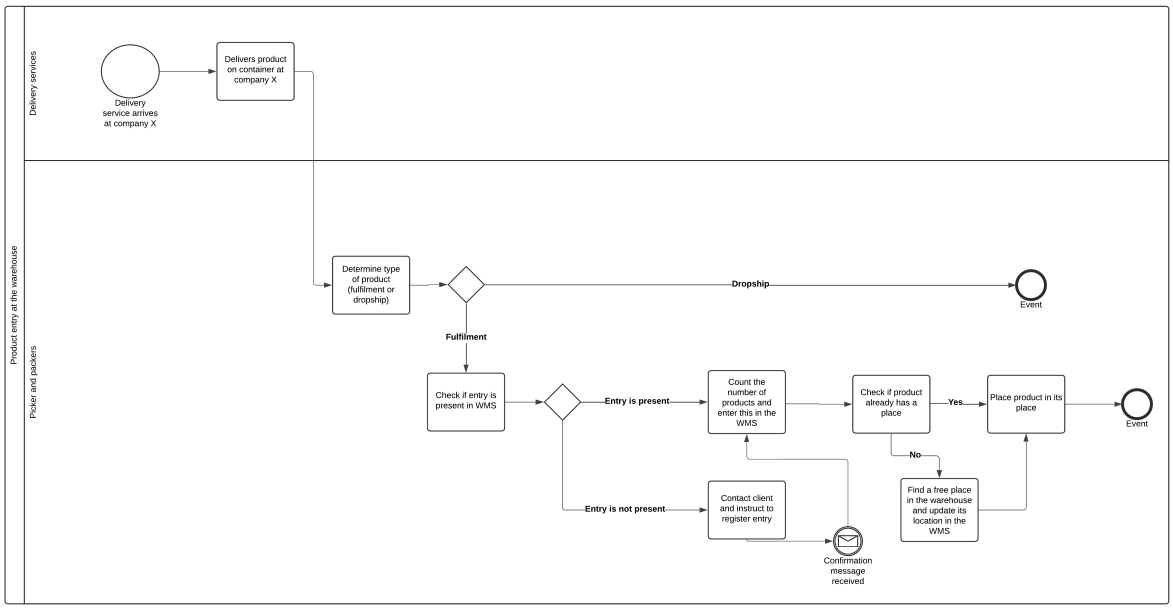

Fig. 14: BPM model of product entry

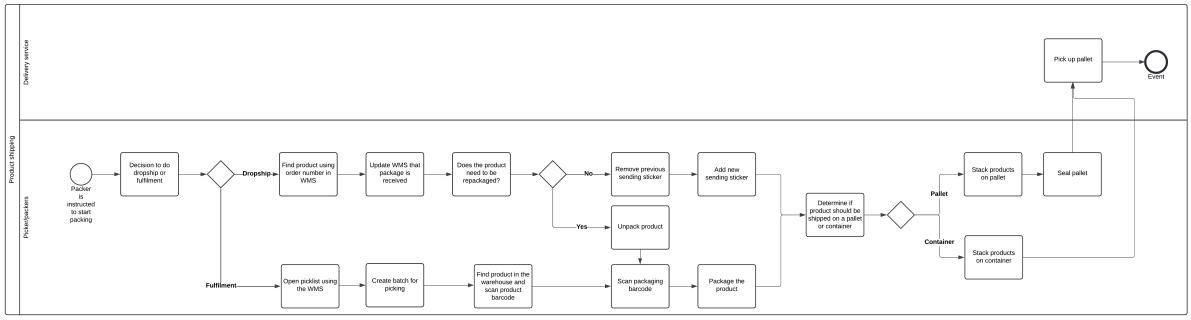

Fig. 15: BPM model of product shipping

3.2 Warehouse equipment

The warehouse contains stored products as well as equipment such that the products can be stored. The equipment allows the operations to be performed efficiently. The storage spaces are the most important but the other equipment that is required will be discussed in this section.

Packing tables The packing table in the warehouse is used to package all the products. On the table there is a laptop dedicated to using the WMS. After packaging, the products can be stored on containers to easily move products to the pallets.

In the current situation there are two packing tables in the warehouse. In the other warehouse the decision can be made to increase the number of packing tables. The new warehouse is significantly larger which means that walking distances will increase which leads to wasted time during the picking process.

Picking cart The order picking cart mentioned previously in section 3.1 will be used in the new warehouse. An order picking cart is used to collect multiple products in one run [7]. Using a picking cart will lead to less time spent walking towards products as a batch can be collected in one run. There are different picking carts which have advantages and disadvantages. The decision has to be made about the number of carts and what types of carts.

To analyse the picking carts the requirements for these carts has to be determined first. The purpose of the order picking cart is to reduce walking distance during the order picking process. A decision to make for the pick carts is using separated bins in the picking cart. The advantage of having multiple bins is that several picklists can be processed at the same time [11]. The alternative is a picking cart with one big storage area where all the products are temporarily stored.

The second thing to pay attention to is the size of the cart. A larger cart makes it easier to store a lot of products which will reduce the walking distance more than a smaller cart. A larger cart is more difficult to

move through the warehouse as it needs more space to move.

In the current warehouse there are never more than two order pickers working at the same time. The quantity of picking carts should be based on the number of order pickers working in the warehouse. Therefore the warehouse requires two order picking carts in order to function efficiently.

As two picking carts are required it will be wise to get two different picking carts who both have their own specialisations. One picking cart should be specialised in larger products and one cart should have smaller storage spaces specialised for smaller products.

Roll container Roll containers are used as temporary storage spaces in the warehouse. Roll containers are used by delivery services who place the products on a roll container. The other use case is for placing products that are packaged. Using the roll container the products can be moved to the loading dock where the pallets are built. Roll containers are used for storing products during transport as they can easily be moved in or out of a truck.

Warehouse stacker The warehouse stacker [7] is a popular tool used in larger warehouses. The new warehouse will be higher than the current warehouse, which will allow for higher storage racks. In order to access these storage racks the warehouse stacker is a necessity as the new warehouse is seven metres high. The main requirement for the warehouse stacker is the height. Additionally, the turning circle and the battery life are important attributes for selecting the right warehouse stacker.

The warehouse stacker has to have a height of at least six metres as the warehouse is seven metres high. The stacker does not need to have the entire height of the warehouse as the product/pallet is lifted from the bottom.

The warehouse needs one warehouse stacker as this machine will not be used by multiple employees at the same time. The stacker will not be used regularly in the warehouse. It is a machine that has very specific usecases which allows pallets/products to be stored using the full height of the warehouse.

Loading dock The loading dock is the place in the warehouse where products enter and leave the warehouse. From the loading dock containers are moved into the warehouse and the product entry can start. The pallets that are made for shipping are stored close to the loading dock, this enables the delivery services to bring the pallets to their trucks without having to walk far. The loading dock is a pressure point in the warehouse as congestion can be observed daily. The congestion happens at the loading dock as there is not enough space to store all the pallets that have to be shipped while maintaining breathing room to perform the tasks. At the end of the working day there are many pallets which have to be shipped which are stored at the loading dock. These pallets do not have a dedicated place and take up space which can better be used for performing the activities. These pallets have to be stacked by the employees with the products that have been picked and packed. The stacking on the pallets requires space to stack the products and seal the pallets. Sealing the pallets is putting plastic around the products such that the products do not fall over.

The first dedicated part of the loading dock has to do with the product entry which is done using the roll containers owned by the company. The delivery services store the products on the containers or if there

is no space, products are stored on the floor. This is not desirable which is why the company wants more space such that products are always stored in one of the containers. After the products have entered the warehouse the product entry has to be performed so positioning the containers close to the storage will save time.

3.2.1 Current inventory

The company already owns a lot of equipment which will be moved into the new warehouse. Using this equipment makes sense as this saves a lot of costs. The next table will give an overview of what equipment is already owned by the company. The custom closets are not shown in the table as the company does not own these closets yet.

Table 1: Overview of current warehouse equipment

Storage method	**Size**	**Quantity**
Pallet storage	120x80	60
Shelf rack/rack with dividers	90x45	19
	100x80	6
	120x80	3
	155x60	2
	115x50	1
	230x65	4
	280x110	4
Packing table	240x90	2

The pallets are used for bulk storage which means that every pallet serves as one location and can store one product. The desired size of the shelf racks is 120x80 as this is the same size of a euro pallet. Using shelf racks of this size leads to the pallets, custom closets and shelf racks all being the same size. This will lead to a more cohesive and organised warehouse.

3.3 Summary

To summarise this section the research question mentioned in section 1.3 will be answered. The first question to answer is:

- What activities are performed daily at company X?

The activities that are performed daily are mentioned in subsection 3.1. The activities that are influenced by my research are the product entry and the order picking. The product entry process will change as the classification discussed later will be used to assign products to the corresponding storage method. Using the classification will make the process easier as more guidance is provided. The product entry will also be more consistent as the same logic for assigning storage places is used every time. The process is not changed but the difference will be noticeable.

The next question to answer is:

- What equipment is required for performing these activities?

All the equipment that is required in the warehouse is discussed in subsection 3.2. The equipment that is required but not owned yet are the picking cart and the warehouse stacker. The warehouse stacker is required for utilising the full height of the warehouse. The picking cart is used to reduce the number of trips required to pick the products. Important to note is that the picking cart is not a necessity, however using the cart will make the warehouse more efficient.

To investigate how to make the warehouse more efficient the next question is answered:

- What are time wasters happening currently?

The main time waster that was found is the retrieval of products from storage. This problem was addressed by the managers and the employees. This suspicion was confirmed by trying the retrieval myself. For most of the product in the warehouse the retrieval takes no time at all. However, for some of the products the retrieval is not direct, indirect retrieval is deemed as excessive. Another time waster is the congestion that happens at the loading dock. The congestion makes performing tasks more difficult which costs time.

The last question to answer is:

- What equipment should be acquired when moving to the new warehouse?

As discussed previously a warehouse stacker has to be acquired to utilise the height of the warehouse. As the new warehouse is larger more previously mentioned packing tables have to be acquired. Currently, there are two packing tables which is not enough. The management of the company wants a packing table at the end of every aisle in the warehouse. The new warehouse will have five aisles which means that at least three new packing tables have to be acquired.

4 Classification framework

The products have to be classified in order to assign the right storage method to the product. This section covers all the information required to perform this classification for products in a warehouse. The classification of products is all about assigning products to the appropriate storage space. The chapter starts with researching different types of attributes that describe a product in the warehouse. After all the attributes have been collected a selection is made of attributes that will be used for the classification framework. As the company does not have information of products with relevant attributes this data has to be gathered manually. Creating this dataset is time consuming, which is why gathering many different attributes is not desired. Especially if attributes end up not being relevant for the research this is a waste of time.

After the attributes are established this part explains how to gather the different attributes and how to calculate these attributes. There are attributes which can be gathered by observing the product. Other attributes are calculated using attributes that are observed or measured.

The dataset is created with products and their attributes. The dataset is used to analyse the products in the warehouse based on their attributes. The data is analysed by creating clusters of products that have similar characteristics. The clusters are used to determine the storage methods that are required in the warehouse. To move towards a new warehouse decisions need to be made regarding the types and quantities of storage methods. These decisions will be based on the current inventory of company X. Another part of this section is a tool that assigns products to the appropriate storage method, this tool can be used for current and new products in the warehouse.

4.1 Attributes

In the attributes section the attributes will be collected using three different methods; literature search, observation and a panel meeting. Once the methods are collected the appropriate attributes will be selected.

4.1.1 Gathering methods

Three methods have been used to collect attributes about the products, these methods are literature search, panel meeting and observation. Three different methods were used to not miss out on any possible attributes. The first method was literature search to find most of the attributes that are standard or have been used by others before. Secondly, the panel meeting will be used. The co-managers are specialists and know more than me about attributes to use. Lastly, the products will be observed by me to make sure no attributes will be forgotten. This method serves as a final check.

Literature search The first attributes have been found by performing a literature search using databases Scopus and Web of science. The search queries used contained the terms: "warehouse","SKU", "classification", "characteristics" and "fulfilment". These terms were chosen as these terms are related to finding attributes. The literature search was performed to find possible attributes to use for the classification. The first source that was found was by Fontana [5]. This source bases the location assignment of products in a warehouse on physical attributes of the products. This source was useful as the classification is similar to my own research. Other sources were found focusing on topics that were relevant for my research. These sources include papers by: Savsar [10], Angerer [1], Ettouzani [4], DeHoratius [3] and Usman [12]. The papers all

had specific subjects to focus on which lead to finding additional attributes. Through these papers it was found that the physical attributes of a products are the key factor for determining the appropriate storage method. The selected attributes that were found are shown in table 2.

Appendix B contains a table with all attributes with their description, how to gather, unit of measurement, source and if the attribute is used for classification or not.

Attribute	**Description**
Weight	The weight of the product (grams)
Demand	The number of products that are sold per month
Variation of demand	The extent to which the demand can vary every month (X,Y,Z)
Demand patterns	Certain changes in demand based on seasonality, date events etc.
Shelf life	The average amount of time a product is in the warehouse
Handling requirements	Special requirements for handling products in the warehouse
Storage needs	Special requirements for storing products in the warehouse
Promotion activities	Promotional activities performed by a company which can lead to fluctuating demand
Product price	The price of the product
Availability at the DC	How easily a product can be obtained from the distribution center

Table 2: Attributes found through literature

Observation Another method used was observing the warehouse and the products it contained. After finding the attributes through literature I was looking for additional attributes that could describe the products in more detail. The attributes found can be seen in table 3

Attribute	**Description**
Stackability	The degree to which a product can be stacked
Length	The length of the product
Width	The width of a product
Height	The height of a product
Volume	The size of a product found by multiplying the length, width and height of a product
Surface area	The size of a product found by multiplying the length and the width

Table 3: Attributes found through observation

Panel meeting Together with the two co-managers I held a panel meeting to brainstorm about additional attributes which are important for the company. The meeting started with me explaining the purpose of the meeting and the attributes that were already discovered. As a number of attributes had been gathered already, the focus revolved around finding attributes that are company specific. I tried to give the managers an idea of what attributes could be useful so that they could think of additional attributes. I tried to push

them to find attributes that were company specific with information that cannot be found online. The attributes that were found are shown in table 4.

Attribute	**Description**
Lyra rating	The WMS gives a rating based on demand and variation of demand
Client	The client that which sells the product
Already packaged	The state in which the product arrives in the warehouse
Packaging type	How the product needs to be packaged before shipping
Contribution margin	Some products are cheaper than others based on client loyalty

Table 4: Attributes found using the panel meeting

4.1.2 Selection of attributes

During the gathering of the attributes I found that most attributes can be divided into attributes about the layout of the warehouse and attributes about the storage of products. After reviewing the attributes I made a selection of attributes that will be the most useful for my own research. Attributes were selected when two requirements were met. The attribute should influence the way of storing products and the attribute should be objectively measurable. Attributes that are important for the place in the warehouse will be disregarded in this section. The classification framework has the goal of determining the appropriate storage methods for a product. Even though the layout of the warehouse is important, it is not the goal for this section of the research. For example the demand of a product is an important attribute to determine the place in the warehouse. However, this attribute does not determine how a product will be stored and will therefore not be used in the classification. The attributes that are dropped are:

Demand, variation of demand, demand patterns, shelf life The demand, variation of demand, demand patterns and shelf life were dropped as these do not influence the storing method. These attributes can influence where to store a product in the warehouse to increase efficiency in the warehouse. For example, two pieces of clothing can have completely different demand patterns or variations in demand. Even though these products are completely different for these attributes the products will still be stored using the same storage method. This is why they were dropped for this classification.

Promotion activities The promotion activities attribute is dropped as it is not relevant for the classification framework. These activities could influence the place to store the product, however the method of storing the product will not change. Promotional activities can influence demand and inventory as sales are likely to increase when products receive a discount.

There is one situation where the promotion activities and the previously mentioned attributes would matter. For products that move super fast the decision can be made to pick products directly from the pallet. This can be done for products that move fast in high quantities. The decision is made to not regard this specific situation in the framework. This decision is made because of two reasons, the first reason is that this situation is rare. It does not happen often which means that it is not a priority. Secondly, if a products moves fast it can easily be observed in the warehouse. Because it is not a priority and the situation can easily be recognised it is not taken into account in the classification framework.

Availability at the DC This attribute is not applicable for the situation of company X. Company X's task is to store and ship products that get delivered by their clients. The availability of products does not matter for company X which is why this attribute was dropped.

The first data collection was performed using the attributes that were not dropped. After performing the collection of data and analysing the results it was found that these attributes are not as useful as initially anticipated. The reasons for dropping these attributes will now be explained.

Weight The weight of a product is a good attribute to describe a product using the physical attribute. After observing the product when creating the initial dataset it was found that the weight is not an important attribute when determining the storage method. The storage methods that have been discussed in section 2.2.2 are sturdy and can handle significant weight.

Another reason for dropping this attribute is because of the correlation between the weight and the volume of a product. For example, the big products that are stored on pallets are also the heaviest products. The weight of a product can be too heavy for the custom closet. However, in the data set the products that were heavy were also too large. That is the reason that this attribute was not further used.

Handling requirements During the data collection it was found that there were no products that had special handling requirements in the warehouse of company X. Even though this attribute is important it is not applicable to the situation of company X.

Price This attribute is dropped for the same reason as the weight attribute, the price differs but not significantly. There are products which can be classified as expensive, but no product is so expensive that it requires additional storage requirements. Again, there can be products which require additional storage requirements. These prodcuts are not present in the warhouse which is why the attribute is dropped.

Storage needs This attribute was dropped as there were no particular storage needs observed in the warehouse. Potential storage needs that were anticipated earlier were not found, and therefore this attribute was dropped.

4.2 Final attributes

Now that certain attributes have been dropped and added the final attributes can be selected. The final attributes can be divided in two categories, attributes to collect and attributes to calculate. The attributes to collect can directly be determined by observing or measuring the product. The calculated attributes are based on the collected attributes and provide information that is required for making decisions. Both types of attributes will be used for the classification, but collecting the data should be performed with as few attributes as possible in order to speed up the process. As mentioned the data is collected using a google form with input fields for the attributes. This method is further explained in section 4.2.1. For example if the length and the width are collected, the surface area can be calculated in another column using a formula. The attributes that are collected manually are:

Length, width and height These attributes describe the products using their physical attributes. These attributes will be collected by measuring the products in the warehouse. Collecting these attributes was chosen over collecting the surface area or volume as these can be calculated using the three basic attributes. These attributes may sound basic but these attributes can be used to calculate the size and shape of the product.

Stackability The last attribute is the stackability of a product. The stackability has been mentioned previously and during observation it was found that this attribute was the most informative in determining the type of storage space. The stackability of a product is a score which describes how easy a product can be stacked. This attribute determines if a products needs a specialised storage method or not. A product that can easily be stacked (stackability score of A) does not require a specialised storage method. While a product that cannot be stacked properly (stackability score of C) requires a specialised storage method in order to be stored efficiently. The stackability score of B is between the other two, this score is given to products that can be stacked but might fall over when too many products are stacked. Even though the size of the products can be the same, the storage method can be different. Because of this reason the stackability was found to be an important attribute. The categories can be A,B or C and are used to determine the storage method.

After determining these attributes the calculated attributes using the previously gathered attributes are:

Surface area The surface area is a useful attribute to determine the 2D size of products in the warehouse. The surface area will be calculated using the length and width.

Volume This attribute is very similar to the surface area however it is calculated by using the height of the product as well.

There are two more attributes which are used in the classification framework: the shape; and the size. These attributes are not used in the clustering performed in subsection 4.3.1. The two attributes are used in the classification tool to determine the appropriate storage method for an individual product.

Shape The shape of the product is calculated using the length, width and height of the product. It was found that using one formula for determining the size of a product was not correct as it lead to unreliable results. There were big differences in determining sizes for products which had different shapes. Flat products would not be classified as large as the height is very small. Even though a flat product can definitely be large, without having a large height. The shape is not an attribute directly used for classifying products, however it is an essential attribute to calculate the size. Section 4.3 explains how to calculate the shape of a product.

Size The size of a product is based on the sizes of the storage methods. The purpose of the size attribute is to assign a product to the storage method. It makes sense to label a product as small when the product fits the smallest storage method. The size is based on boundaries for the length, width and the height.

4.2.1 Data collection

The data used for the research was collected by measuring and observing products in the warehouse. Every product was collected by storing the name, length, width, height and stackability score. All the entries were

saved in a sheet which allowed the creation of additional columns to calculate the surface area and volume of all the entries. After the collection was done this file was downloaded as a CSV (comma separated value) file which allowed me to analyse the data.

The data collection was an important step in gathering information about the inventory of the company. As there is no information this step is essential for answering the research question.

4.3 Calculation of attributes

The calculated attributes are calculated by using the collected attributes. The calculations will be based on logic as well as data analysis. The attribute that can be calculated using logic is the shape attribute of a product.

Shape The shape of the product is determined by the length, width and height. Finding the best metric started out with comparing the volume with the surface area. This method gave varying results as a large surface area can have a larger height and still be considered flat. While a small surface area only allows for a lower height. The second method considered was absolute minimums/maximums. This lead to the problem that shapes with different sizes of length and width gave problems during the classification.
The final solution is created by using the average of the length and the width to create a more accurate metric.

$$Height < \frac{Length + Width}{10} \tag{2}$$

When this condition is met the product can be classified as flat. The second shape is determined in the same way but changing the formula. A product can be classified as tall when the following formula holds.

$$Height > \frac{Length + Width}{2} \tag{3}$$

In the case that both of these conditions are false, the product is considered to have a regular shape. Products can have more shapes than flat, tall or regular, the shape is used to calculate the size of a product. For the size it matters how much space is required for a product, therefore the exact shape is not relevant.

Size For the size an additional column will be created where the size can be small, medium, large and very large. Four categories are chosen as there are four sizes of storage methods. The size will be based on boundaries that are based on the sizes of the storage methods.

The initial plan to determine the size of a product was to use the volume as a metric to determine the size. It was found that the volume in itself is not a very good metric as the shape influences the volume significantly. For example a flat product can be very large but the volume can be low which is why using just the volume is not a good metric.

Another idea was to base the size on data in the dataset. This is a approach that would work, but the size of a product is used to choose the storage method. Basing the size of a product on the storage method is more useful. None of these approaches produced the desired results. The boundaries for the sizes are determined in section 4.5.1 using the results of the clustering explained in subsection 4.3.1.

4.3.1 Data analysis

The decision was made to create six different clusters of products. The end goal for the new warehouse is to create a warehouse that is versatile. The main challenge is to create a versatile warehouse without having too many different storage methods. Having more than six different methods was discouraged by the management. Six was considered as the sweet spot as this provides plenty of different storage spaces while still having an organised and simple warehouse.

The different clusters will now be analysed to find appropriate storage methods for the different clusters. The goal of the analysis is to find characteristics that differentiate the different products. The analysis starts with creating a table with a summary of the clustering created by Orange. Secondly, figure 16 contains the first 30 entries of the data set with the corresponding cluster. The results of this subsection are summarised in a table where the characteristics of the different clusters are shown.

Cluster/Average	**Length**	**Width**	**Height**	**Surface area**	**Volume**
Cluster 1	75.5	49.0	39.0	3722	143376
Cluster 2	39.0	29.6	1.6	1160	1713
Cluster 3	57.9	46.9	2.4	2765	6540
Cluster 4	22.1	15.0	6.5	346	1806
Cluster 5	31.5	18.9	6.5	629	5303
Cluster 6	20.5	12.5	34.4	297	11594

Table 5: Summary of clustering by Orange

	Cluster	Length	Width	Height	Stackability=B	Stackability=C	Surface area	Volume
1	C6	20	30	50	1	0	600	30000
2	C4	13	12	22	0	0	156	3432
3	C4	17	8	8	0	0	136	1088
4	C4	28	23	12	1	0	644	7728
5	C4	34	10	9	0	0	340	3060
6	C4	17	10	12	0	0	170	2040
7	C4	9	4	10	0	0	36	360
8	C4	43	15	7	0	0	645	4515
9	C4	24	19	9	0	0	456	4104
10	C4	18	16	5	0	0	288	1440
11	C4	13	15	8	0	0	195	1560
12	C4	33	19	12	0	0	627	7524
13	C4	39	18	9	0	0	702	6318
14	C4	22	19	6	0	0	418	2508
15	C4	33	10	5	0	0	330	1650
16	C4	12	12	13	0	0	144	1872
17	C5	30	28	14	0	1	840	11760
18	C4	20	20	20	0	0	400	8000
19	C4	16	10	6	0	0	160	960
20	C3	45	38	7	1	0	1710	11970
21	C4	22	15	6	0	0	330	1980
22	C2	29	29	6	0	0	841	5046
23	C4	12	9	5	0	0	108	540
24	C4	15	15	31	0	0	225	6975
25	C4	15	15	4	0	0	225	900
26	C4	15	10	4	0	0	150	600
27	C4	19	6	3	0	0	114	342
28	C4	14	8	5	0	0	112	560
29	C4	20	20	1	0	0	400	400
30	C5	22	13	3	0	1	286	858

Fig. 16: First 30 entries of products attributes with the corresponding cluster.

The appendix contains box plots of the attributes per cluster. The information in table 5 is based on the box plots in appendix B.2. For comparing the different clusters I have used these box plots as a visual aid to understand the differences and characteristics of the clusters.

Cluster one Cluster one stands out as this is the cluster that has the largest products. The length, width and height attributes all have the highest average value compared to the other clusters. Cluster one only has products with a stackability score of "A", this means that the products can be stacked well. The products in cluster one can be characterised as very large and well stackable.

Cluster two and three Cluster two and cluster three are similar in terms of their characteristics. Both clusters have a very small average height. This in combination with having a relatively large surface area means that the products are flat. The difference between the two clusters is that cluster three has on average

larger products than cluster two. In the data table it is found that the products in both clusters can be stacked well. Cluster two can be characterised by medium sized products that are flat and well stackable. Cluster three can be characterised by large products that are flat and well stackable.

Cluster four and five Cluster four and five are similar in terms of the length, width and height attributes. The products cannot be deemed as flat or tall and are therefore treated as regular products. In the data table it can be seen that the small products in the data set are in clusters four and five. The key differnce between the two clusters is that cluster four contains products that mostly have a stackability rating of "B" while products in cluster five mostly have a stackability rating of "C". So, the products in cluster four are small to medium sized and can be stacked but not well. The products in cluster five are small to medium sized and can be stacked poorly.

Cluster six Cluster six stands out as it contains products where the height attribute on average has a higher value than the length attribute. Cluster six is the only cluster where this is the case. Another characteristic of the cluster is that the product in this cluster are difficult to stack, almost all of the products have a stackability score of "C". The challenge for this cluster is that the sizes of the products vary significantly. For example; the lowest height value is around 20cm while the highest value is around 50cm. To characterise this cluster, the products are tall that can be stacked poorly and the size ranges from medium to large.

Cluster	**Size**	**Stackability**	**Shape**
Cluster 1	Very large	Good	Other/rectangular
Cluster 2	Medium	Good	Flat
Cluster 3	Large	Good	Flat
Cluster 4	Small/medium	Decent	Regular
Cluster 5	Small/medium	Poor	Regular
Cluster 6	Medium/large	Poor	Tall

Table 6: Table with the characteristics of the different clusters

4.4 Choosing the storage methods

In this section the storage methods to use in the warehouse will be selected based on the different characteristics of the clusters. The storage methods will be selected from the theoretical framework (section 2). The goal of this classification is to find appropriate storage methods for products. After this is completed a decision tree will be made to determine the storage method for a particular product. For every cluster the requirements for a product will be discussed to ensure that every product is classified properly. Before the storage methods are selected here is an overview of the characteristics of the different storage methods.

4.4.1 Analysing the clusters

Storage method	**Suitable for**	**Compartment size**	**Customisability**	**Organisational capabilities**
Pallet storage	Very large products that can be stacked well	Very large	None	Limited
Shelf rack	Small to large products that do not require support to stay in place.	Large	None	Decent
Shelf rack with dividers	Small to large products that require little support to stay in place.	Small/medium/ large	Decent	Good
Custom closet with small compartments	Small products that require support to stay in place. Products do not need to be stackable.	Small	Good	Excellent
Custom closet with medium compartments	Medium sized products that require support to stay in place. Products do not need to be stackable	Medium	Good	Very good
Custom closets with horizontal removable planks	Small/medium sized products that have a tall shape and cannot be stacked.	Small/medium	Good	Very good

Table 7: Overview of characteristics of storage methods

Cluster 1 Cluster three contains very large products that can easily be stacked. The storage method that fits best is pallet storage as the products can easily be stacked and the products require a lot of space. Currently, these products are stored on pallets and this works well. The products in this cluster are heavy so pallet storage is the only method appropriate for this cluster.

Cluster 2 Cluster two contains products that are flat and can be stacked well. For the products in this cluster large storage spaces are required as the surface area of the products are large. Custom closets are not a good fit for these products as their specialisation lies in smaller products. The best storage method will be the shelf rack. These shelf racks are larger than the closets and have enough space to store the flat products of cluster four. To improve organisation, the earlier mentioned dividers can be used. The idea is to place the products between two dividers to fixate the products to enable efficient stacking.

For cluster two and three the requirement is the same, the shelf rack cannot be used if the product has a length or width that is too large. The largest shelf rack is 280x110 cm, this means that if the length exceeds 280cm or the width exceeds 110cm (measurements in this research are performed such that length ¿= width) the product cannot be stored in a shelf rack. Important to note is that products of this size are rare so it is not a priority to think about.

Cluster 3 The next cluster is cluster three which contains flat products just as cluster two. The difference is that cluster three only contains products that have a larger surface area than prodcuts from cluster two. The products from cluster five can be stored using shelf racks, again using dividers is a good idea to increase organisation in the warehouse.

Cluster 4 Cluster four contains products that cannot be stacked and have a small size. The products in cluster four are difficult to stack so additional storage capabilities are required. The decision between shelf racks and custom closets is based on the stackability of the products in the cluster. Shelf racks require good stackability for small products to efficiently use the available storage space. Custom closets are more flexible as the small compartments can efficiently store small products with poor stackability. For the custom closets the option to have tilted shelves makes sense for these products as this decreases the chances of products falling out of the compartment. As the products are small the compartments of the closets have to be small to efficiently store products in cluster four.

My logic differs slightly with the clustering that was created. Cluster two also contains small and medium sized products that are easily stackable. These products do not require a storage method with additional capabilities such as a custom closet. Currently, these products are stored in shelf racks. The problem with this method is that not all the available space is utilised. This is because too much space is reserved for a single product. To solve this problem the shelves could be split into small sections, using the previously mentioned dividers. This will allow for storing more products on a single shelf which leads to more efficient use of available space.

The decision is made to store small product with a stackability of "A" on shelf racks even though this interferes with the clustering. The advantage of storing the product on shelf racks is that it is cheaper.

Cluster 5 The next cluster is cluster five. The difference between cluster four and five is the size of the products, cluster five has larger products than cluster four. The storage method and closets will be similar for these products, however the compartments for cluster six have to be larger.

The same alteration holds for cluster five as for cluster four. Medium sized products with a stackability of "A" can better be stored in a shelf rack instead of using a custom closet.

One thing about the clustering of cluster five I do not agree with is the variation of sizes in cluster five. This can be seen in appendix B.2. The products have been clustered together but I think there should be a difference between medium sized products and large products in cluster five. Large products will not fit in the custom closets and could better be stored in shelf racks. This difference will be shown in the decision tree.

Cluster 6 Cluster six contains tall products which have difficulties being stacked. High storage spaces are not efficient for these products as the height of a storage space cannot be utilised. The ideal storage method for these products is a storage method with relatively low compartments such that the storage space can be used efficiently. After consulting section 2.2.2 the custom closets are the best fit. Shelf racks are currently used for the products in this cluster. The storage space used is not efficient as the products are either not stacked which leads to vertical space not being used. The other method is that products are stacked in

a "pyramid" shape which does not use all the available space. The custom closets can be customised, for cluster six the type of closet can be customised to have many different levels such that the closet is specialised for tall products. The closets also have the option to have removable horizontal planks. This option will be used when a product is taller than the compartment such that those products can also be stored efficiently.

The requirement for this cluster is that a product can be "too" tall. For example a product that is 200cm high will not fit the closet, regardless of how many shelves are removed. That is why the requirement for cluster one is that the height cannot exceed 50cm. This number is based on the fact that the compartments of the custom closets can be made tall but the compartments exceed 50cm.

4.4.2 Decision tree

Every cluster has its own characteristics, these characteristics have been used to assign the appropriate storage method to the clusters. However, the clustering produced good results but not all products were assigned to the appropriate storage method. The decision tree will solve this issue by slightly changing the logic used by the clustering algorithm. The characteristics that will be used for the decision tree are the size, shape, stackability. These attributes were combined with the requirements for storing products in a storage method. The decision tree is created to create the python script discussed in subsection 4.5.2.

The decision tree starts with the question: "What is the shape of the product?" followed by the question: "What is the size of the product?". This is because the storage method of the product is based on the shape and size of a product. The order of these two questions can be changed, as the question about shape had less possible outcomes the decision was made to ask this question first to create a more concise decision tree (first question has three options instead of four). The decision tree consists mainly of the logic explained in subsection 4.4. However a few additions are made to create more accurate results. The additions that are made are discussed now.

Height limit for tall products For products that are considered to have a tall shape the recommendation is to store these in custom closets that have compartments that can be adjusted in size. However, there is a limit for the height of the products. When a products exceeds the limit of 50cm, storing the product in a custom closet is not viable anymore. The product will then be stored in a shelf rack because these have higher compartments.

Small products in a storage rack Another addition is the storage of small products with a stackability rating of "A". These products were clustered together with small products that cannot be stacked. I discussed this with the management and we agreed that these small stackable products are better stored in the shelf racks. This decision was made because products that can easily be stacked do not require the storage support that a custom closet offers.

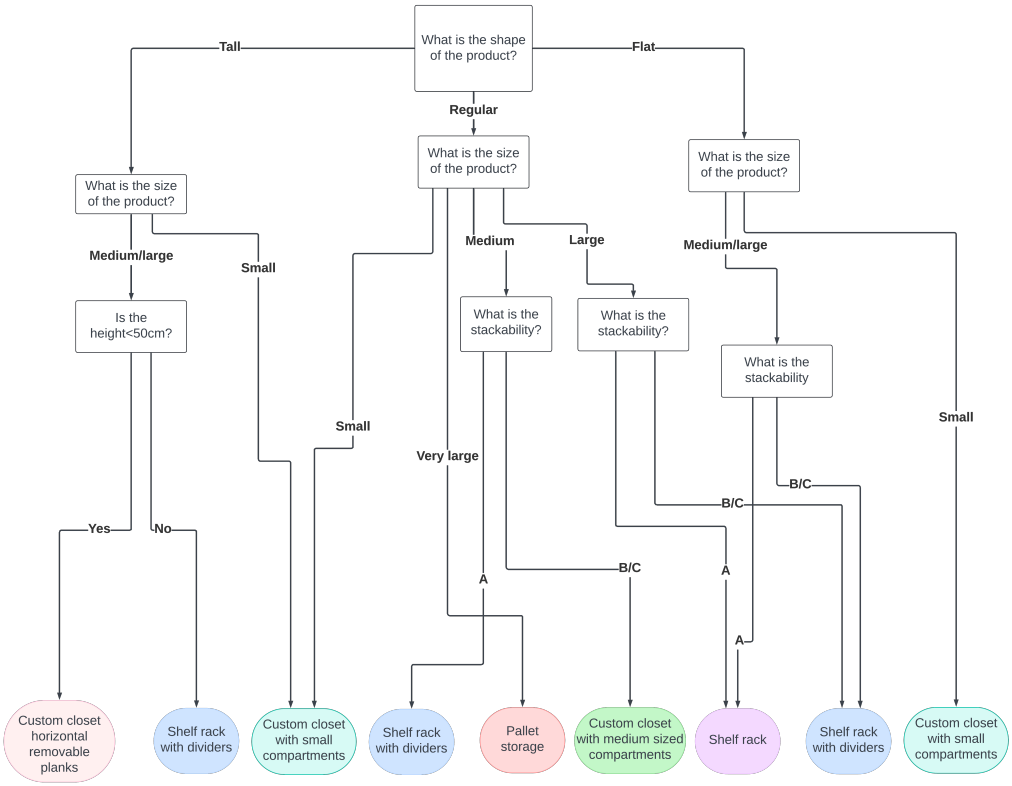

Fig. 17: Decision tree

4.5 Sizes of storage spaces

The appropriate storage methods have been selected and an individual product can now be connected to the appropriate storage method using the decision tree. In this section the quantities of storage methods will be determined. The quantities of storage methods are important as these serve as recommendations for the company. The clustering by Orange is a good starting point, but the clustering cannot directly be used, as fine tuning the results is still required. The decision tree shown previously is the end result which has to be implemented in a short script. This script will connect products to their respective storage method based on the decision tree.

4.5.1 Determine boundaries for size

The problem with implementing the decision tree is determining the size of a product. During the analysis of the clusters it was clear which clusters were larger than others, by comparing the clusters the sizes were determined. For the script this method will not work as absolute boundaries need to be established.

The approach for determining the boundaries will be to base the boundaries on the sizes of the storage methods. The section starts with discussing the size of the different storage methods. Based on the size of the method the boundaries are established. This is performed for every storage method.

Pallet storage Pallet storage does not have a size restriction for the products on a pallet, as this method is the largest storage method that is available. The euro pallet has a size of 120x80cm and products can be stacked high on the pallet. Products that do not fit on a pallet cannot be shipped as the carriers do not allow this. Therefore, there is no size constraint for pallet storage.

Shelf rack Shelf racks have different sizes and different sized shelf racks are used in the warehouse. In the new warehouse all storage spaces will be in pallet storage racks. For this reason the shelf rack size will be similar to the size of a euro pallet which is 120x80 cm. Shelving racks are used to store multiple units of a single product. For the calculations we will assume a minimum number of three products per shelf, the motivation for this is that if less than three products fit on a shelf it would be better to store the products using pallets. In that case pallet storage would be better as storing multiple units on a pallet is more space efficient than using a shelf rack.

When at least three products have to be stored on a shelf the length cannot exceed 80cm and the width cannot exceed 40cm. Lastly, the boundary for the height has to be established. The height of a storage space in a shelf rack is not fixed. The shelves can be changed in height, the height in the current situation is 50cm. Therefore, the boundary for the height of products in a shelf rack cannot exceed 50cm. The boundaries for a large product are:

$$\begin{aligned} \text{Length} &\leq 80\text{cm} \\ \text{Width} &\leq 40\text{cm} \\ \text{Height} &\leq 50\text{cm} \end{aligned} \tag{4}$$

Custom closets with medium sized compartments The next storage method to discuss is the custom closet with medium sized compartment. For the custom closets there are many possibilities as the closets can be custom made. Additionally, the closets have the ability for planks to be removed to increase the size of compartments.

On all different versions of the custom closets. The custom closets can be made to have the size of a euro pallet which is useful for storing the closets in the warehouse. A closet that is 80cm deep does not make sense as this will not be accessible. To place two closets on one pallet a depth of 40cm allows for openings on both sides of the closet. The width of a closet will be 120cm to have the same length as a euro pallet. The height can be changed according to the needs. As the closets are treated as the size of pallets the height will also be based on the height of a pallet. In the warehouse the height of the pallet racks is 180cm, the closet has to fit this height. Additionally, the closet will be used for the picking of products. Therefore, the

products in the closet should be accessible for all pickers in the warehouse. The closets can have a height of 180cm which is accessible for all order pickers so this is the height of the closet.

The sizes of the compartments are based on section 4.3.1 where the numerical attributes of the clusters are shown. The compartments should be large enough to store multiple units of one product. To allow for multiple products in one compartment the size of the compartments is 40x40x30cm. This size creates eighteen equal sized compartments that can be used for storing medium sized products.

Now that the sizes of the compartments for medium sized products are determined, the boundaries for a medium sized products are found. The length and width of a product cannot exceed 40cm and the height cannot exceed 30cm. The boundaries for a medium product are:

$$\begin{aligned} \text{Length} &\leq 30\text{cm} \\ \text{Width} &\leq 40\text{cm} \\ \text{Height} &\leq 30\text{cm} \end{aligned} \tag{5}$$

Custom closets with small sized compartments The last storage method to discuss is the custom closet with small sized compartments. The size of the compartments is based on the data shown in section 4.3.1 for cluster two.

Again, the depth of the closets has to be 40cm. The height of products of cluster two are small, on average a height of 2.84cm. As products with a small height have to be stacked lower compartments would be beneficial to maintain organisation and prohibit the units from falling. As the closet has to remain versatile the height of the compartments is 15cm. This height allows for storing the products of this cluster with a larger height as well as efficiently storing products that have a small height. The width of a compartment has to be a bit more as the average width is 15.09cm. The width of the compartment will be 20cm to allow for efficient storage of small products as well as enabling the larger products of cluster two to be stored in these compartments.

Now that the size of the compartments is determined the boundaries can be established. The length of these products cannot exceed 20cm, the width cannot exceed 20cm and the height cannot exceed 15cm. The boundaries for a small product are:

$$\begin{aligned} \text{Length} &\leq 40\text{cm} \\ \text{Width} &\leq 20\text{cm} \\ \text{Height} &\leq 15\text{cm} \end{aligned} \tag{6}$$

4.5.2 Decision tree script

A script is created to assign products to its corresponding storage method based on the classification. The script is based on the decision tree and the section 4.5.1. The decision is made to create a Python script as I already have experience with this programming language through the course data analysis and programming by Dr. Alves Beirigo. Python is usable with csv files which is needed for my research.

The Python script uses the data file as input and adds a column to the data file that contains the appropriate storage method according to the decision tree. The script contains a number of different functions which

will be discussed next.

The first function determines the shape of a product by using formulas 2 and 3. If one of the conditions is met the product gets the corresponding label and if neither condition is met the products gets the regular label. The formula looks like this:

```
# ====================================
# shape function
# ====================================
# create a shape label for every product
def categorize_product_by_shape(row):
    if (row.Length + row.Width) / 10 > row.Height:
        return flat
    elif (row.Length + row.Width) / 2 < row.Height:
        return tall
    else:
        return regular
```

Fig. 18: Shape function

The second function determines the size of the products by using the boundaries mentioned in subsection 4.5.1. The function first check the boundaries for products that are small. When these requirements are not met the check is performed for medium products and lastly the check is performed for large products. If none of the requirements are met the products are classified as very large. The formula looks like this:

```python
# ==================================
# size function
# ==================================
# variables length
length_small = 30
length_medium = 40
length_large = 80

# variables width
width_small = 20
width_medium = 40
width_large = 40

# variables height
height_small = 15
height_medium = 30
height_large = 50


def categorise_product_by_size(row):
    if row.Length <= length_small and row.Width <= width_small and row.Height <= height_small:
        return small
    elif row.Length <= length_medium and row.Width <= width_medium and row.Height <= height_medium:
        return medium
    elif row.Length <= length_large and row.Width <= width_large and row.Height <= height_large:
        return large
    else:
        return very_large
```

Fig. 19: Size function

The last function determines the appropriate storage method for a product using the labels assigned by the two previous mentioned functions. This function uses the logic from the decision tree to assign the storage method. The formula looks like this:

```
# ====================================
# storage function
# ====================================
# requirements
flat_storage_max = 50

def categorise_product_storage(row):
    if row.Shape == flat:
        if row.Size == small:
            return CC_small
        else:
            if row.Stackability == "A":
                return shelf_rack
            else:
                return shelf_rack_dividers
    elif row.Shape == tall:
        if row.Size == small:
            return CC_small
        elif row.Height < flat_storage_max:
            return CC_horizontal_removable
        else:
            return shelf_rack_dividers
    else:
        if row.Size == small:
            return CC_small
        elif row.Size == medium:
            if row.Stackability == "A":
                return shelf_rack_dividers
            else:
                return CC_medium
        elif row.Size == large:
            if row.Stackability == "A":
                return shelf_rack
            else:
                return shelf_rack_dividers
        elif row.Size == very_large:
            return pallet_storage
        else:
            return default
```

Fig. 20: Storage method function

The script created a file that contained all the products with their corresponding storage methods. A histogram is created displaying the storage methods with the number of products connected to the respective storage method. The histogram can be seen in figure 21.

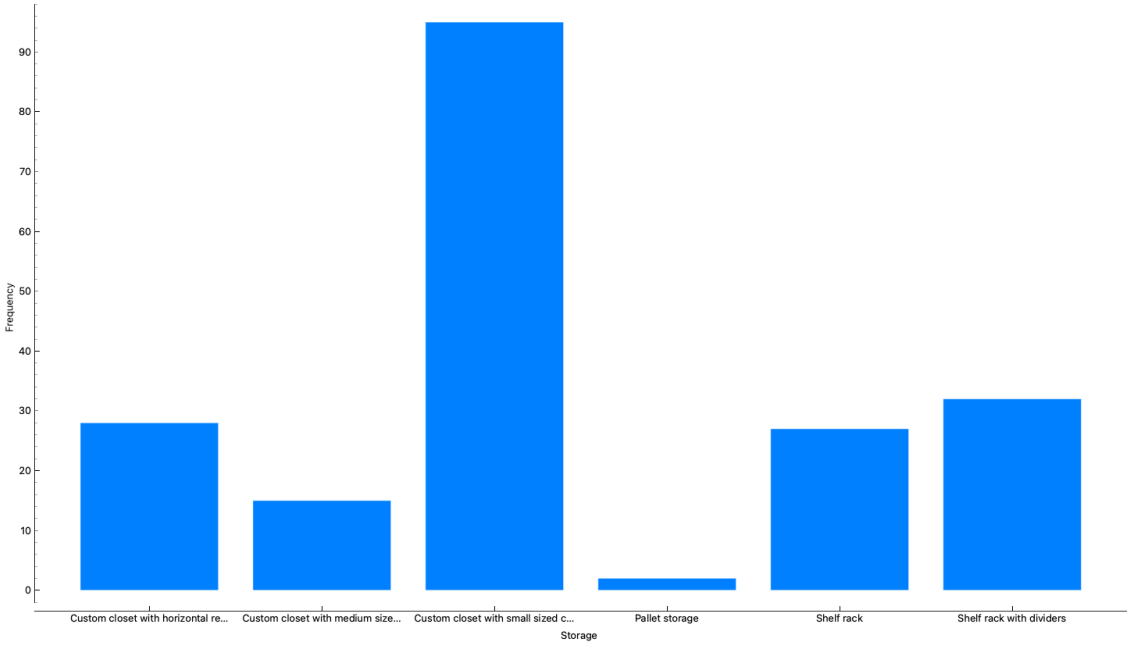

Fig. 21: Histogram storage methods

The percentages of the products per storage methods can be seen in table 8. The two things that stand out is that most of the products have to be stored in the custom closets. The custom closets with small compartments are the most important as almost half of the products are best stored using these types of closets.

Storage method	**Percentage of products**
Custom closet with small sized compartments	47.74
Custom closet with medium sized compartments	7.54
Custom closet with horizontal removable planks	14.07
Shelf rack	13.57
Shelf rack with dividers	16.08
Pallet storage	1.01

Table 8: Table with percentages per storage method

4.6 Summary

Company X has many different products in the warehouse. The inventory is always changing, however categories are made to classify different products in the warehouse. The products will be split into the shapes tall, flat and regular and in the sizes very small, small, medium, large and very large. This leads to a total number of fifteen different categories which will be used to assign the corresponding storage method. Many different attributes have been discussed in this section to differentiate different products in a warehouse. Most of the attributes mentioned can be used, however the important attributes for company X are the shape, size and stackability. The length, width and height of a product are used to determine the width and the size. The products will be connected to the previously mentioned storage methods using the shape, size and stackability. In this section certain rules have been established to connect products to their optimal storage method. The decisions can be found in figure 17. The decisions were based on the managers expertise as well as using knowledge from section 1.3.

This section is summarised by answering the research questions mentioned in section 1.3. The first two questions to answer are:

- What attributes can be used for products in a (fulfilment) warehouse to differentiate products?
- What attributes are used for categorising the products.

The attributes were gathered using three different methods discussed in section 4.1.1. Not all attributes are used in the classification framework. The reasoning for dropping individual attributes can be found in section 4.1.2. The attributes that were used in the classification framework are:

- ◇ Length
- ◇ Width
- ◇ Height
- ◇ Surface area
- ◇ Volume
- ◇ Stackability

These attributes are used to describe and differentiate products by using attributes that are important for products in a warehouse. Attributes that were dropped, were dropped because of relevance, usability or the attribute does not have added value. For example the weight attribute was dropped as there was a strong correlation between the volume and the weight of a product.

The last question the needs to be answered is:

- How to connect attributes of a product to a suitable storage method?

The answer to this question is a summary of almost the entire section. It starts with clustering the products in the warehouse using hierarchical clustering. This part was performed to determine the storage methods required in the warehouse. The selection of storage methods was made based on characteristics and storage requirements of the clusters, the analysis can be found in subsection 4.4.1. After the storage methods were

determined a decision tree was created to assign an individual product to a storage method. This decision tree was based on the clusters created previously. Alterations were made for clustering decisions that were wrong or confusing. Decisions that were made are discussed in section 4.4.

After the decision tree was made boundaries needed to be established. These boundaries are used for determining the size of the product. The clustering already used the dimensions to cluster the products, however determining the size of a product should also be possible for a new product entering the warehouse. To solve this absolute boundaries needed to be established, new and old products can now be connected to the appropriate storage method. The sizes are based on the sizes of the storage methods. This decision was made as the size is used to connect the product to the appropriate storage method. Now that the size boundaries were established the script was created to connect every product in the data set to a storage method as well as the possibility to perform the calculations for a new product.

5 Recommendations/Conclusions

In this section the findings of the research are presented to help company X organise their new warehouse. The recommendations are based on the findings found in the different chapters of the research. The company has to make the decisions regarding the investments, quantities, types etc. The goal of the recommendations is to enable the company to make informed decisions with predictable results. The possible decisions are presented with the implications of the possible decisions. Additionally, the recommended decisions are motivated to make the decision making process as effortless as possible. The recommendations cover the storage methods and the equipment in the warehouse.

5.1 Storage methods

The decisions that need to be made regarding the storage methods are about the types and quantities of storage methods. The recommendations are based on the data set previously discussed in subsection 4.3.1. The section starts with discussing the storage methods to acquire in the warehouse.

Pallet storage The company already owns 60 pallets which is enough for the current situation. In the new warehouse there is a lot more space for storing pallets as these can be stored in the pallet racks above the picking area. Pallets are often acquired for free by keeping pallets used for sending packages or taking pallets offered by a delivery service. The recommendation would be to keep doing this as having more pallets is good for the storage capacity. There are no disadvantages to having empty pallets as these can be stored easily.

Pallets can also be stored directly on the ground which is a good temporary/budget solution to increase storage space without the need for storage racks. As pallets are easily obtainable and the current inventory of pallets is enough, the recommendation would be to not buy new pallets as it is unnecessary. In the future it will be important to monitor the number of free pallets so that new pallets can be ordered in time. However, if free pallets are available this is always a good idea.

Shelf racks The company already owns a number of storage racks which can be used in the new warehouse. As these racks are already owned by the company it would be a waste to not use these in the new warehouse. There are many different sized storage racks in use, the company desires more cohesion in the new warehouse. When new storage racks are acquired these will have the same size (120x80 cm) to create more cohesion in the warehouse. The storage racks are currently used for all products stored in the warehouse. In the new warehouse the small and/or hardly stackable products will be stored in the custom closets so the storage racks only need to store larger products or products that are easy to stack.

As the shelf racks now have to store less different products the larger storage racks become more desirable. The most suitable size for the shelf racks is the 120x80 cm. This option is the best as it is the same size as a euro-pallet and the same size as the custom closet. This will lead to an organised warehouse as all the storage options are the same size.

The depth of the shelf rack allows a number of storage options. For smaller products the rack can have picking locations on both sides of the storage rack. A divider can be placed in the middle to keep the different picking

locations separated. The other option is that just one side can be used as a picking location. This is a good practice when products are bigger and require more space. The recommendation would be to buy new shelf racks when the additional storage space is required. The definition of "storage space is required" can change depending on what is valued in the company. As efficiency is required the turning point for extra storage space is way before every storage rack is full. An efficient warehouse has to be organised which means that storage racks cannot be fully packed. The storage racks have to be monitored by checking if space is available if a customer would bring products. If there is no space available there is a need for new storage racks.

Custom closets The company does not own any custom closets yet. The custom closets are required in the new warehouse to store the small, medium and difficult-to-stack products. The three types of custom closets that are chosen are the closet with medium sized compartments and upward facing planks, small size compartments with upward facing planks and medium sized compartments with horizontal removable planks. The types of closets were selected based on the clustering performed in section 4.3.1. The closets can have custom sized compartments. The sizes of the compartments are based on the sizes of products in the different clusters. The recommended sizes of the compartments together with argumentation can be found in section 4.5.1. The different solutions discussed in section 5.3 provide the information required to make the decision.

Important to note is that the size of a compartment influences the number of compartments. For example the small closets are 20x15 cm would be changed to be 30x15 the number of compartments decreases from 72 to 48 which is significant. The current sizes are based on the current inventory. The company may disagree if significant growth of certain products is expected.

For the custom closets there is a minimum order quantity per type of closet. The exact number of closets have to be decided by the company. However, in figure 21 it is shown that most of the products require the small compartments. This information is useful, but a closet with small compartments has more storage spaces than a closet with medium sized compartments. This means that the figure can be used to get an overview of the types of products in the warehouse, however it cannot directly be linked to the number of closets to acquire.

The minimal order quantity of closets is seven. The recommendation is to acquire closets that have different sized compartments on both sides. This creates the opportunity to store two types of products in one closet. Lastly, a possible solution that was discovered by discussing was to create three different sizes of compartments to store all possible sizes efficiently. The management liked this solution as this solution seems very logical. The solution presented in this research is based on the current inventory ensuring validity of the results.

5.2 Components of the warehouse

The components of the warehouse are required to have a functioning warehouse. Everything that is required in the new warehouse will be discussed with how to select the right option for the warehouse.

Packing tables In the new warehouse more than two packing tables are required. The packing tables have two requirements, there needs to be enough space to comfortably pack the products and the packaging material needs to be within hands reach of the packer. The current packing tables have a size of 240x90

which is the desired size for the packing tables.

> The packing tables in the new warehouse should have a packing station connected to the packing table. A packing station is an extension of the table which can hold materials that are used at the packing table. The packing station will allow the packer to have the packaging material within hands reach when standing at the packing table to speed up the packing process. There are fifteen different packaging options which are currently stored using a big storage rack where all the packaging material is stored. In the new warehouse the aisles will only contain certain sizes, this idea was introduced by the management to create a more organised and efficient warehouse. Another idea was to place a packing table at the end of every aisle in the warehouse. As a packing table will only be used for a limited number of sized products, this means that the packing tables do not need all the packaging material in the packing station.

Fig. 22: Example of a packing table

For the fast-pick area discussed previously, there is one special packing table, namely the packing table in the fast-pick-area. This table should be more versatile than the other packing tables as more different products are stored in this fast-pick area.

Picking cart Using a picking cart is a decision that needs to be made as it is not required to have a functioning warehouse. The recommendation is to use a picking cart as this will lead to a significant reduction in distance to cover for the order picker, which will lead to quicker picking times. As mentioned in section 3 the company requires a minimum of two picking carts. For the picking carts the decision needs to be made about the size of the compartments in the picking cart. The size of the picking cart also depends on the number of picking carts in the warehouse. If the decision is made to purchase more picking carts the more specialised the carts can be made. In the optimal situation there will be four different picking carts, one for every row. The picking cart will then be optimised for the type of products that are in that aisle. If the decision is made to purchase three picking carts there has to be a picking cart with small compartments, one with medium compartments and one with large compartments. Lastly, if the decision is made to purchase two picking carts there has to be a cart with large and medium sized compartments and one picking cart with small compartments.

Fast-pick area A fast-pick area is not a physical component of the warehouse, but it is used to organise the warehouse. A fast-pick area is a dedicated place in the warehouse where the most popular or fastest moving products are stored. The research by Kong and Masel [8] provides a guide on how to organise the fast-pick area in a warehouse. If company X decides to opt for a fast-pick area, two recommendations can be useful. The first recommendation is to position the fast-pick area close to the loading dock. This increases efficiency as a large number of products are picked in the fast-pick area. These products do not need to be transported far as they are already located close to the loading dock.

The second recommendation is to store many units of a product in the fast-pick area. A disadvantage of the fast-pick area is that products need to be replenished f no more units are available. Storing more units of a single product will lead to less replenishing of products. Determining how many products to store has to be done by observing how often products need to be replenished. When a products has to be replenished more products have to be stored in the fast-pick area.

The two managers of the company know which products move the fastest, they can determine which products should be stored in the fast-pick area. Additionally, the order pickers can be consulted as the order pickers are the ones that experience the inefficiencies first-hand.

As the company has to move to the new warehouse a layout is created to help the company place everything in the new warehouse. The sketched layout of the warehouse can be seen in figure 23 and a larger image can be found in appendix B.3.

Anonymised

Fig. 23: A sketched warehouse layout

5.3 Quantity of storage spaces

In the new warehouse there is enough space to store all the products that are currently stored in the warehouse. The company needs to know how many storage spaces are required to store all the products efficiently. The required number of storage spaces is a decision that varies per person and can be subjective. The decision depends on what the company considers as important. That is why there will be different estimations based on what the company might consider as important. The different recommendations will be economical,

organisational and minimal.

The economical solution will focus on storage spaces that cost less and have a lot of capacity. Organisation and quality are not focus points for this solution. The organisational solution will focus on having clear separated spaces for every product. As every product has its own space the retrieval will be fast and order picking times will decrease. This solution will not be as cheap as the economical as there is more space required to store the products. The optimal/dream scenario for the company has enough space for all products to be stored in a separate storage space. However this solution will also incorporate more tailored solutions which will increase capacity but will also increase costs. Lastly, there is the minimal solution. The minimal solution will focus on the required capacity to store everything.

Minimal solution The minimal solution will provide the numbers to store what is currently in the warehouse. These numbers are based on the findings displayed in table 1. Additionally in the unorganised bulk storage space there are 30 pallets in use to store the slow moving products. The storage methods to use are storage racks as these can be moved from the current warehouse to the new warehouse which means that there are no additional costs.

Organisational solution The organisational solution will focus on creating an organised warehouse without acquiring storage spaces that will not be used. This solution will solve the problem that products are stored inefficiently which leads to significant product retrieval time. Around 30% of products in the data set can be stored using pallets, storage racks or storage racks with dividers. The still leaves 70% of products that have additional storage needs. These products are stored by using the methods mentioned in section 4.4. After researching the different possibilities it was found that most products can efficiently be stored using either closets with medium sized compartments, small sized compartments and medium sized compartments where the horizontal planks can be removed.

The sizes of the different closets have been discussed in section 4.5.1. The conclusion is that medium compartments are 40x30 cm and the small compartments are 20x15 cm. The closets are 120x80 cm, because this is the width of a euro-pallet. The capacity of the warehouse will greatly be increased by using the custom closets. As mentioned earlier the minimal order quantity for the closets is seven, and therefore the recommendation is to have double sided closets.

The custom closets have a large storage capacity, therefore not that many closets have to be ordered. The recommendation would be to order two types of closets. The first type of closet has small compartments on one side and medium sized compartments on the other side. The other type also has small comartments and medium sized compartments on the other side, the different is that these compartments are tilted. These closets are more appropriate for products that slip or fall over. If seven closets of both types are acquired the warehouse will become efficient and organised.

To increase organisation in the warehouse the dividers provided by the company should be acquired. These dividers provide more customisation leading to more versatile closets and eventually a more organised warehouse. These dividers can be placed in compartments to create specific shapes or make smaller compartments.

Economical solution The economical solution will focus on creating an organised and efficient layout while focusing on keeping costs down. The first measure to bring costs down is to reuse most storage spaces

that are already in the warehouse. The different between the economical solution and the organisational solution is that the economical solution only has one type of custom closet. The custom closet will have small compartments on one side and medium sized compartments on the other side, the compartments will be tilted. The compartments are tilted to ensure that all different types of products can be stored. Products that do not fall over can also be stored in tilted closets, products that fall over cannot be stored in regular closets.

The recommendation is to acquire ten closets of this type such that a large number of products can be stored using the closets. This option leads to a lower number of efficient storage spaces which will make the warehouse less organised and efficient. However, this option will be cheaper to implement and will still lead to a more efficient and organised warehouse.

Conclusion The three types of solution will all allow company X to operate a functioning warehouse. It was found that there do not need to be additional investments to keep the company running and functioning. However, the company does not only want a functioning warehouse. The company values efficiency as this allows the company to compete with other similar firms in the region. The best solution for efficiency is the organisational solution. This solution allows most of the products to be stored in their optimal storage space which improves efficiency in the warehouse. The economical and organisational solution are both good options to implement in the warehouse. The main different is the the organisational solution is more tailored to a wider variety of products. The ultimately leads to more efficiency and organisation, however this solution is more expensive and the available capacity might not be used which is a waste.

5.4 Current situation versus new warehouse

This section also investigated the capacity of the custom closets, the organisational solution is compared to the current solution to determine if using this solution is better. As mentioned in table 1 there are a total of 39 storage racks in the current warehouse. In the new warehouse storage racks will still be required so we will start by subtracting the number of storage racks that will still be used in the new warehouse. For the comparison it is assumed that every storage rack can store 12 products, 3 on each shelf and 4 shelves. There are 59 (27+33) products which are stored in a storage rack. This means that a minimum number of 5 storage racks are required. There are products which require more space so for the comparison 6 storage racks are used.

With the closets having a height of 200cm and a width of 120cm there can be 60 small compartments and 20 medium compartments per side of a closet. 95 products require small compartments which means that at least 2 sides of closets are required. Again, there are products which require more than one storage space so 4 sides are required. This is less than the minimum order quantity so the quantity from the organisational solution will be used.

43 (28+15) products require closets with medium compartments. This means that 3 closets are required for the products. Assuming that some products might need multiple compartments 4 closets are required which is less than the minimum order quantity so the organisational solution will be used.

For the new solution 6 storage racks and 14 custom closets are required. This is far less than the current 39 storage racks so this solution is much more space efficient. The difference is this big as the custom closets

are more space efficient.

5.5 Conclusions

In this section three possible solutions have been found to answer the research question. The solutions to the problem serve as recommendations which can either directly be used or as a guideline for the decision making process. The recommendations cover two parts of the warehouse; storage spaces and other components of the warehouse. For company X the storage methods are the most important, which is why the focus of the research is about storage methods. During the research it was found that a warehouse is not just storage, there are many more things to consider.

The issue that was encountered during the research was a lack of documentation of the types of products in the warehouse. This problem was not a goal of the research, but it had to be solved in order to continue the research. The company did not request this information, however the experience was that this information is very useful.

In the new warehouse there are new storage methods that will be implemented. These new methods have been compared to the current situation. It was found that the new methods will increase storage capacity without taking more space in the warehouse. Using the new storage methods is a good idea as more products can be stored per square meter.

The last thing is the improvement of the retrieval of products from the storage spaces. The new storage methods improve organisation, especially the organisation of smaller products. The slow retrieval times have mostly been experienced for smaller products. The improved organisation due to the new storage methods will solve the problem of long retrieval times.

5.6 Further research

The research had to performed in a time span of ten weeks, certain topics had to be dropped to finish the research in time. If more time was available two things would have been performed differently. The first thing is the organisational layout of the warehouse. The layout of a warehouse is an interesting topic when order picking times are part of the research. There are different ways of organising warehouses, where different methods have different advantages. Researching and creating different layouts would have been beneficial for the company, however the time span of the research did not allow for this.

The second thing of the research that was limited was the data collection. The inventory of company X is constantly changing. If the research had a longer time span data could be collected at different points in time leading to a larger data set. This could have lead to more reliable results, however the solutions account for changing inventory and different kinds of products in the warehouse. Additionally, the company has changing inventory but the majority of products stay in the warehouse for a long time. Another example is that a client might replace a product by a very similar product. A client who sells keyboards might change a type of keyboard for another type of keyboard. This changes the inventory but it does not influence the storage method to use.

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A Components of the warehouse

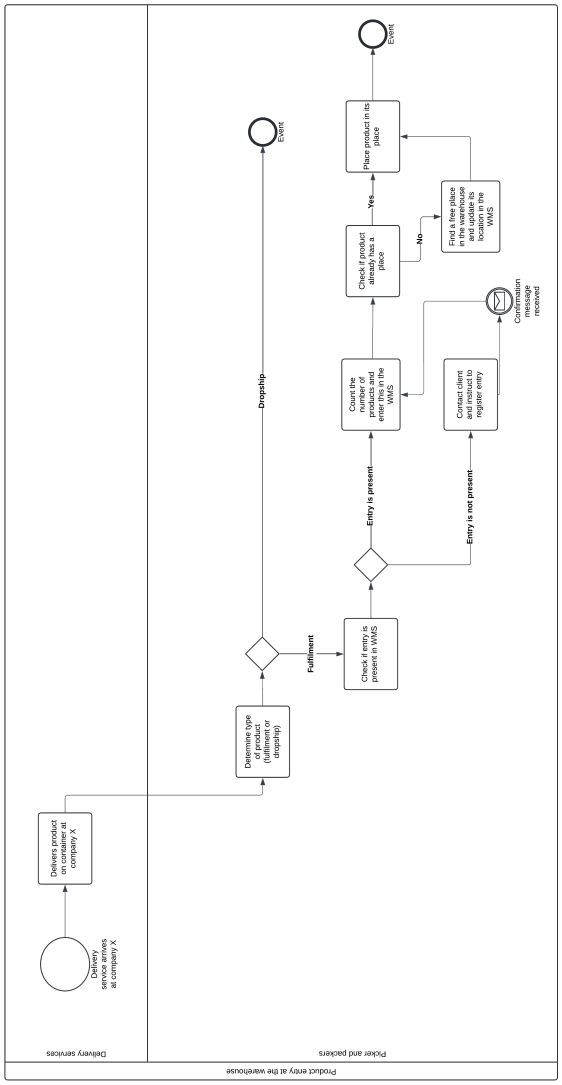

Fig. 24: BPM model of product entry

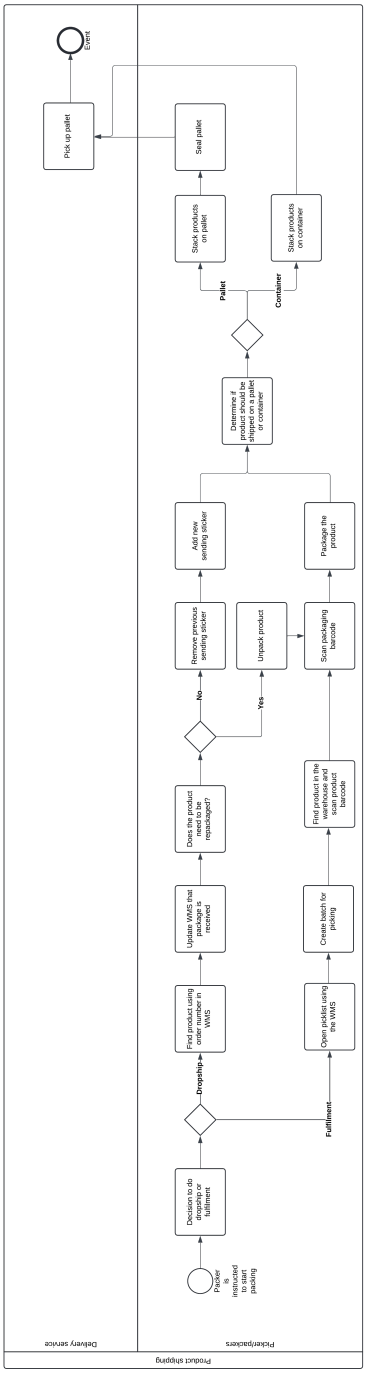

Fig. 25: BPM model of product shipping

B Classification framework

B.1 Classification attributes

Attribute	**Description**	**Gather by**	**Unit of measurement**	**Used for classification**
Weight [5]	The weight of the product	Gather by using a scale	Grams	No
Demand [5]	The number of products that are sold per month	Gather by using WMS	Number per month	No
Variation of demand [5]	The extent to which the demand can vary every month	Gather by using WMS	Can have value X, Y or Z where X is stable, Y is moderate variability and Z is significant variability	No
Demand patterns [10]	Certain changes in demand based on seasonality, date events etc.	Gather by using WMS	Textual expression	No
Shelf life [1]	The amount of time a product is in the warehouse	Gather by using WMS	Days	No
Handling requirements [10]	Special requirements for handling products in the warehouse	Observe the product	Textual expression	No
Storage needs [10]	Special requirements for storing products in the warehouse	Observe the product	Textual expression	No
Promotion activities [4]	Promotional activities performed by a company which can lead to fluctuating demand	Contacting the clients	Textual expression	No
Product price [3]	The price of the product	Gather by using WMS	Euros	No
Availability at the DC [12]	How easily a product can be obtained from the distribution center	Contacting the clients	Textual expression	No

Table 9: Attributes found through literature

Attribute	Description	Gather by	Unit of measurement	Used for classification
Volume	The size of a product found by multiplying the length, width and height of a product	Observing and measuring the product	cm^3	Yes
Surface area	The flat size of a product found by multiplying the length and the width	Observing and measuring the product	cm^2	Yes
Stackability	The degree to which a product can be stacked	Observe the shape of a product	Can have scores A,B,C where A is very easily stackable, B is stackable but not easily and C is not stackable	Yes
Length	The length of the product	Measuring the product	cm	Yes
Width	The width of the product	Measuring the product	cm	Yes
Height	The height of the product	Measuring the product	cm	Yes

Table 10: Attributes found using observation

Attribute	Description	Gather by	Unit of measurement	Used for classification
Lyra rating	The WMS gives a rating based on demand and variation of demand	Gather by using WMS	Can have scores A, B, C + X,Y, Z where X,Y,Z are about variation in demand and A is high sales volume, B is moderate sales volume and C is low sales volume	No
Client	The client which sells the product	Gather by using WMS	Textual expression	No
Already packaged	The state in which the product arrives in the warehouse	Observe the product	Yes or no	No
Packaging type	How the product needs to be packaged before shipping	Observe the product	Textual expression	No
Contribution margin	Some products are cheaper than other similar products based on client loyalty or other things	Contact manager of company	Textual expression	No

Table 11: Attributes found during the panel meeting

B.2 Data analysis

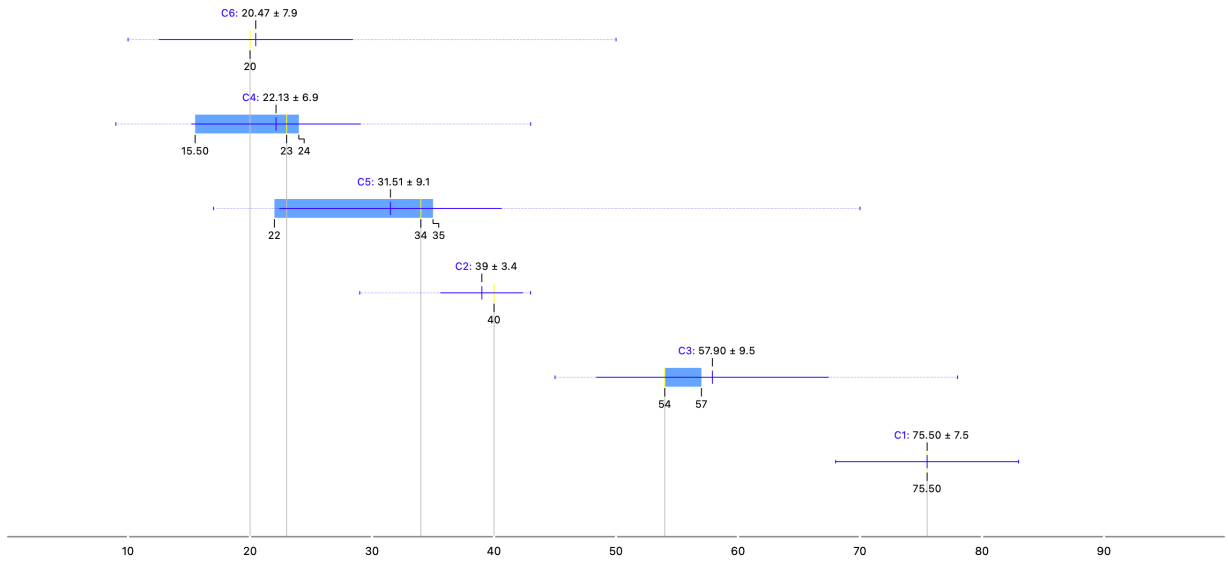

Fig. 26: Box plot of the length attribute

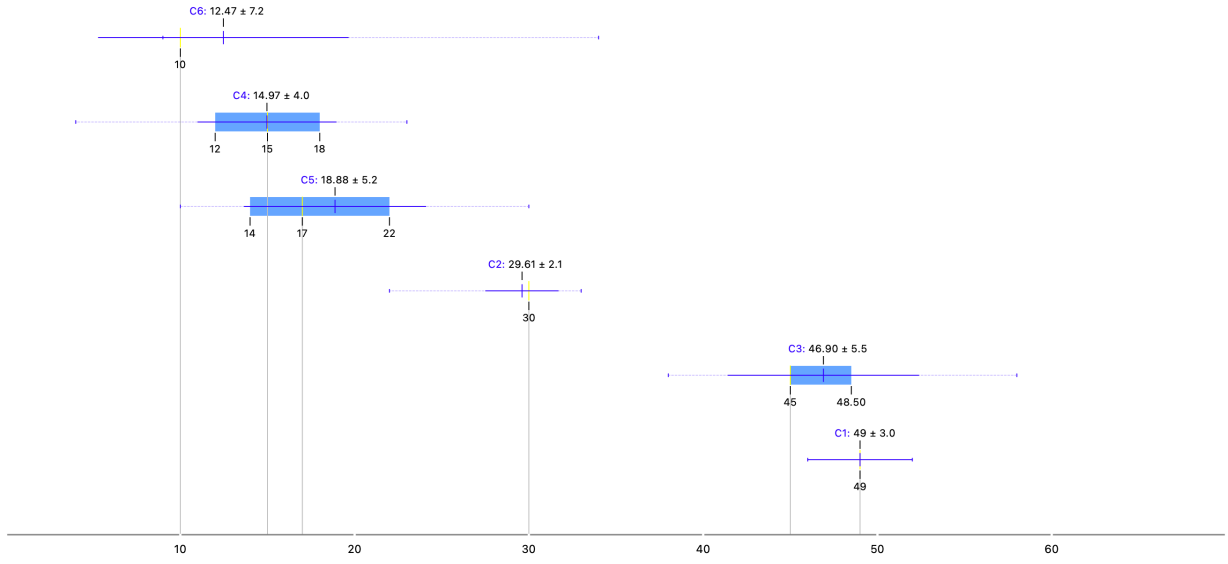

Fig. 27: Box plot of the width attribute

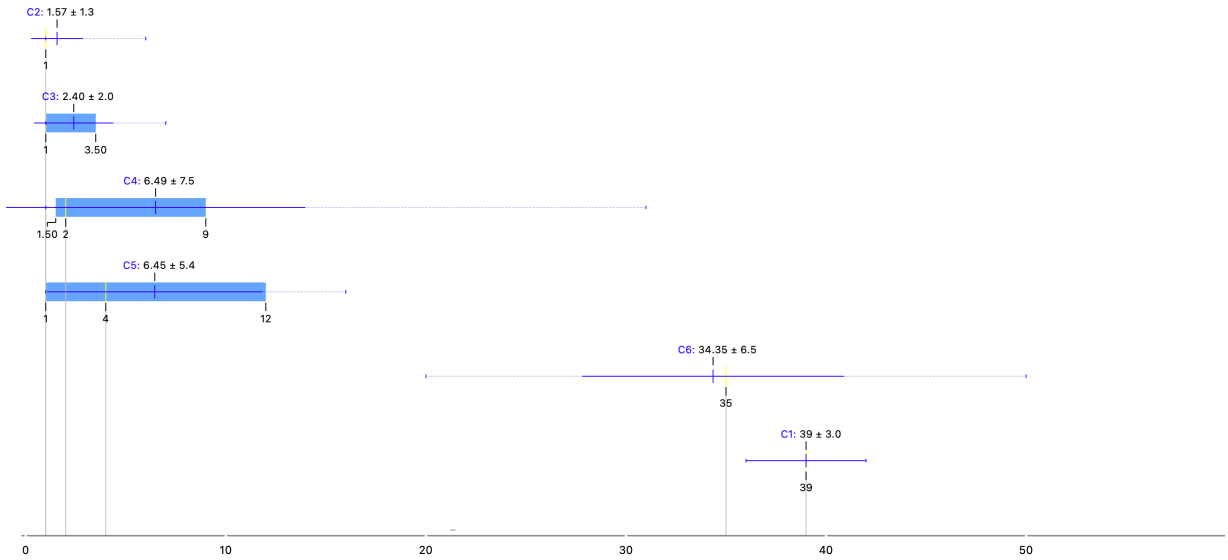

Fig. 28: Box plot of the height attribute

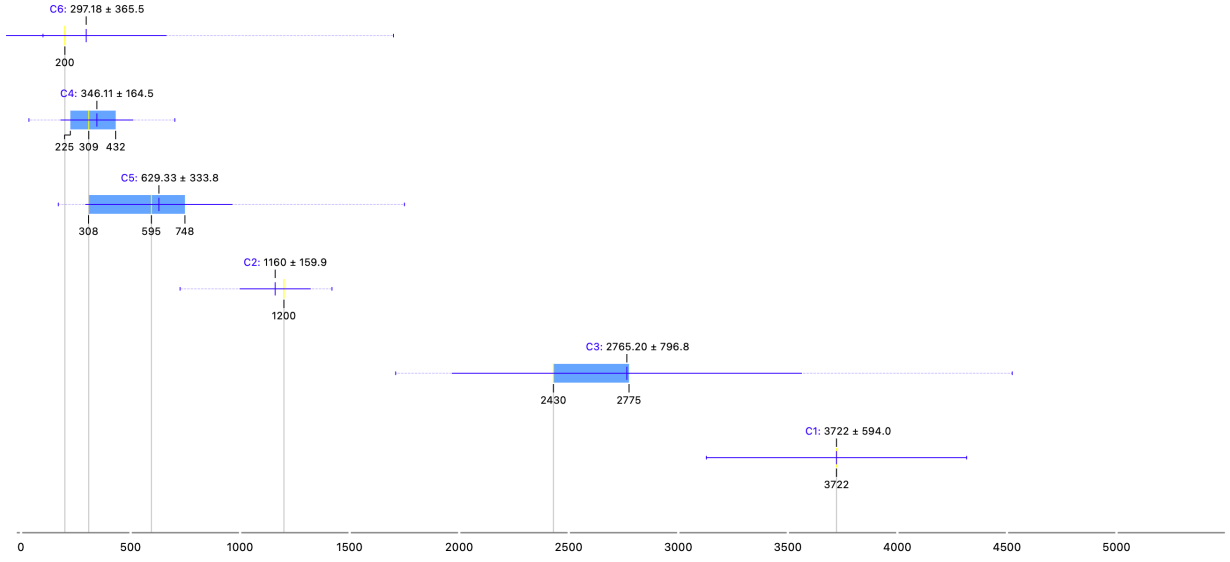

Fig. 29: Box plot of the surface area attribute

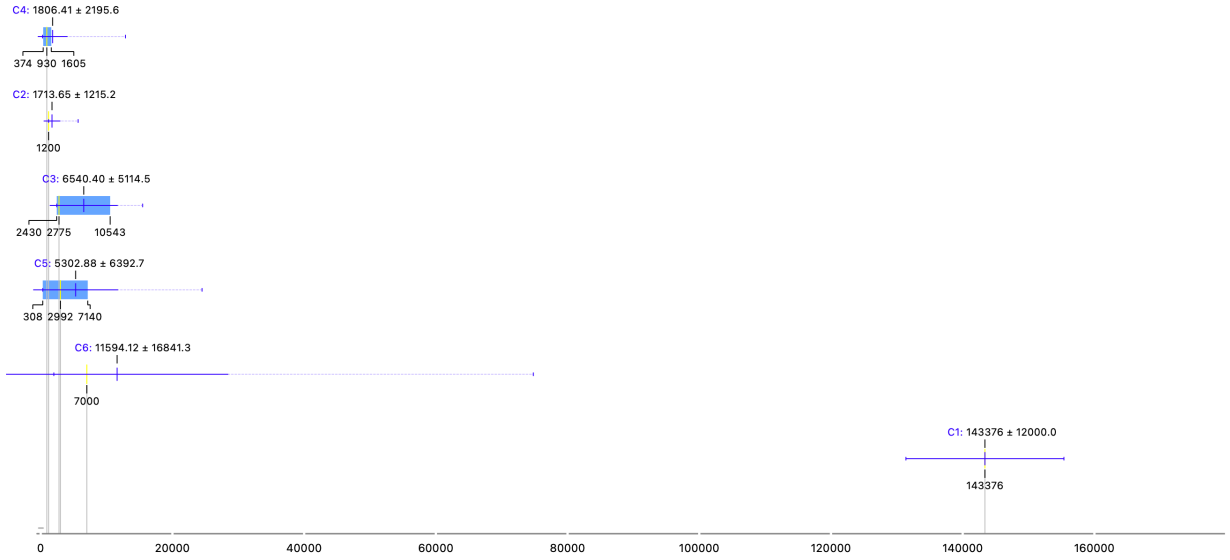

Fig. 30: Box plot of the volume attribute

B.3 Warehouse layout

Anonymised

Fig. 31: Sketched warehouse layout

C Classification using Python

The classification was performed using Python with the Pandas library. The pandas library is what I am familiar with through the data analysis and programming course by Dr. Alves Beirigo. The program takes a comma-seperated value (csv) file as input and returns a csv file with a shape, size and storage column. The shape and size columns are needed to create the storage column. All functions take "row" as input such that it goes through the entire csv file. The functions used will be shown here.

```
# ====================================
# shape function
# ====================================
# create a shape label for every product
def categorize_product_by_shape(row):
    if (row.Length + row.Width) / 10 > row.Height:
        return flat
    elif (row.Length + row.Width) / 2 < row.Height:
        return tall
    else:
        return regular
```

Fig. 32: Function to determine the shape of a product

```python
# ====================================
# size function
# ====================================
# variables length
length_small = 30
length_medium = 40
length_large = 80

# variables width
width_small = 20
width_medium = 40
width_large = 40

# variables height
height_small = 15
height_medium = 30
height_large = 50


def categorise_product_by_size(row):
    if row.Length <= length_small and row.Width <= width_small and row.Height <= height_small:
        return small
    elif row.Length <= length_medium and row.Width <= width_medium and row.Height <= height_medium:
        return medium
    elif row.Length <= length_large and row.Width <= width_large and row.Height <= height_large:
        return large
    else:
        return very_large
```

Fig. 33: Function to determine the size of a product

```python
# ====================================
# storage function
# ====================================
# requirements
flat_storage_max = 50

def categorise_product_storage(row):
    if row.Shape == flat:
        if row.Size == small:
            return CC_small
        else:
            if row.Stackability == "A":
                return shelf_rack
            else:
                return shelf_rack_dividers
    elif row.Shape == tall:
        if row.Size == small:
            return CC_small
        elif row.Height < flat_storage_max:
            return CC_horizontal_removable
        else:
            return shelf_rack_dividers
    else:
        if row.Size == small:
            return CC_small
        elif row.Size == medium:
            if row.Stackability == "A":
                return shelf_rack_dividers
            else:
                return CC_medium
        elif row.Size == large:
            if row.Stackability == "A":
                return shelf_rack
            else:
                return shelf_rack_dividers
        elif row.Size == very_large:
            return pallet_storage
        else:
            return default
```

Fig. 34: Function to determine the storage method for a product