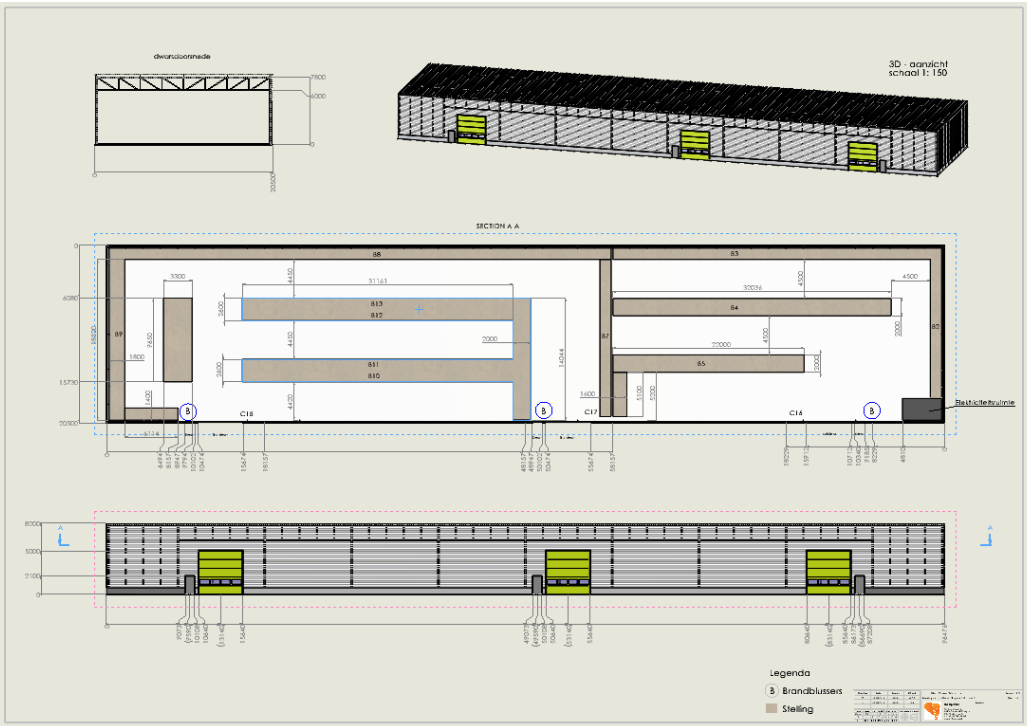
Enlarging the warehouse capacity by improving the layout and the storage policy

Bsc. Thesis Industrial Engineering and Management



Haaksbergen, October 2022

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Preface

Dear reader,

In front of you lies my bachelor thesis "Enlarging the warehouse capacity by improving the layout and the storage policy", which I executed at the companies Tribelt and De Spiraal for my Bachelor Industrial Engineering and Management at the University of Twente. The thesis aims to increase the pallet places and reduce the travel time to be more efficient.

First, I want to thank Tribelt and De Spiraal for giving me the opportunity to execute my bachelor assignment at their company. Especially, I want to thank Rick Peters, who helped me during the process of the thesis and guiding me. I also want to thank all the employees of the companies who always made time for me. Furthermore, I am very thankful that I was allowed to work on the location of the companies.

Next, I would like to thank my first UT supervisor Peter Schuur for his guidance and feedback throughout the research. The feedback helped me to work toward a completed bachelor thesis. I also enjoyed the meetings with him. Also, I would like to thank Berry Gerrits for being my second supervisor and helped me with finishing the last phase of my bachelor thesis.

I hope you enjoy reading my thesis!

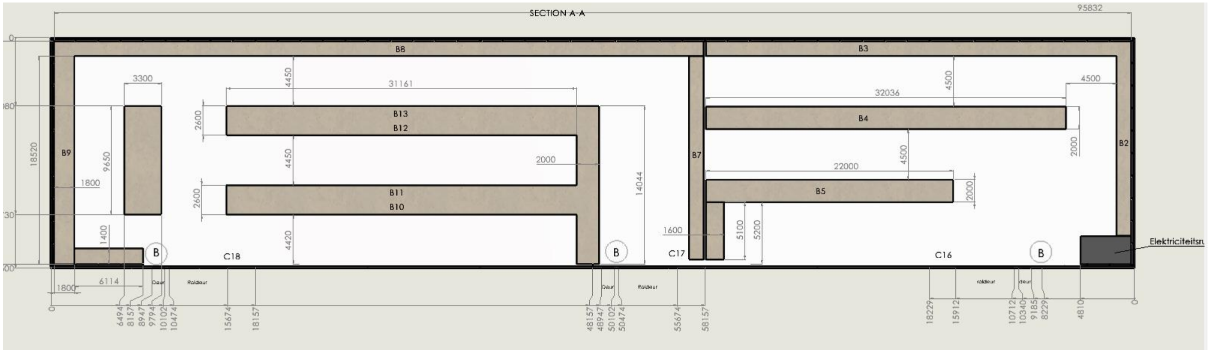
Kim Tijink

Saasveld, October 2022

Management Summary

Motivation

The companies Tribelt and De Spiraal faces the problem that the warehouse is too small for their inventory. The available pallet places are according to them too low for their inventory. The core problem is that the warehouse layout is outdated and currently there is no storage policy. SKUs are stored random because there is no policy. The transport boxes are a huge hinder in the warehouse. The transport boxes are placed in front of the pallet racks, which makes picking a pallet sometimes very inefficient. SKUs are also stored outside, which can decrease the quality of the SKUs. The company thinks the warehouse layout is outdated and the efficiency could be higher. The layout right now can be seen on the figure below. There is much space between the aisles and there are multiple blockages which makes the travel distance very long.



Research question

The research object of this research assignment is smooth product flow and visibility/findability, efficient storage and routing and improving the warehouse layout. The research question is formulated as followed:

How can the capacity of the warehouse of Tribelt and De Spiraal be increased by improving the layout and the storage policy?

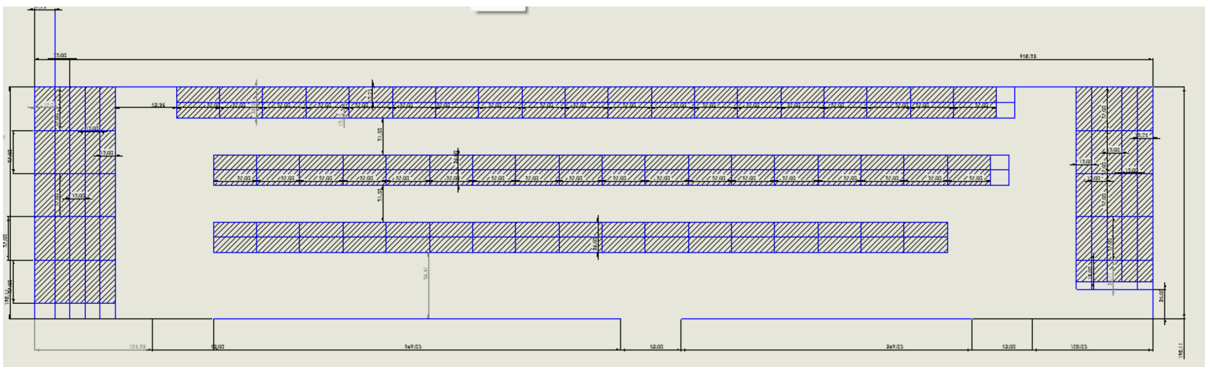
To answer the research question, the current situation was first analyzed, by looking at the current layout and storage policy. The current situation showed that there is no storage policy. The current capacity is 1393 pallet places and space for transport boxes. The in- and outbound is fluctuating a lot in the warehouse. The Pareto-diagram showed that only 11 (Tribelt) and 28 (De Spiraal) per cent of the SKUs in the warehouse cause 80 per cent of the number of receipts.

Methods

The method where is made use of, is the ABC classification. A is designed for high turnover material, B for medium turnover material and C for the least turnover material. This means A are the fast movers and C are the slow movers. There has been made a distinction for this based on the number of receipts per year and these distinctions have to be used in calculating the travel distance. It is possible to apply small aisles when designing a layout, this requires a different kind of truck, but the utilization of the warehouse floor will be higher, which is necessary when creating more pallet places. The goal is to minimize the travel distance made by the employees in the warehouse based on the ABC classification. The travel distance is calculated by Excel files based on the designed layouts. The occupied pallet places in the warehouse are calculated with the mean occupied pallet places in percentages times the total of pallet places. The layout of the warehouse is determined by including various aspects from the literature in the layout. This consist of double deep racking, push back racking, mobile racking, and small aisles between the racks. The methods used, has a higher utilization of the warehouse floor.

Results

The designed layouts show a huge improved on the amount of pallet places which is increased. This is the highest for the layout with push back racking, which increases the pallet places with 80.6%. The layout based on the current situation increases the pallet places with 60.9%. The efficiency in the warehouse can be much higher by putting the fast movers on the shortest travel distance and the slow movers on the longest travel distance. It showed that the travel distance is significantly decreased compared to the current situation for most of the proposed layouts. For three out of the four layouts the travel distance decreased with at least 44.7%. The layout with mobile racks still shows a large travel distance compared to the other proposed layouts and the accessibility is low. The accessibility is currently 100%, this also counts for the layout with small aisles and the layout based on the current situation. The layout with push back racks has an accessibility of 99.1% due to the push back racks of 5 deep. The accessibility for the layouts is high because there are many SKUs in the warehouse that are double. This means that there are more are more pallets of standing in the warehouse. The utilization of the warehouse floor is for all the layouts higher because all layouts show an increase in the pallet places. The KPIs accessibility, travel distance and pallet places are scored for every layout and the highest weighted score of the layouts, is the layout with push back racks. Therefore, we recommend the layout with push back racks. The layout based on the current situation is also potential. The figure below shows the layout with the highest weighted score, the layout with push back racks on the vertical sides.



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Glossary

Abbreviation/concept	Description
SKU	Stock Keeping Unit
AS/RS	Automated storage and retrieval system
SLP	Systematic layout planning
WMS	Warehouse management system
KPI	Key performance indicator

1. Introduction

1.1 Company introduction

The research is performed at the companies Tribelt and De Spiraal. The companies are in the same building in Haaksbergen, where they operate since 2015. The company Tribelt produces mainly conveyor belts for the food, pharmacy, car, and packaging industry. The company De Spiraal produces mainly wire products and springs for medical equipment, industrial and agricultural machines, aviation, and climate technology. The companies are specialized in processing wire and strip steel for more than 70 years. The companies also work together but are branded under another name. Due to this combination of metal conveyor belts with wire products, Tribelt and De Spiraal have everything within reach and fast turnaround time. There is also a warehouse located on the same terrain. Since May 13, 2019, the companies are part of Lesjöfors Springs & Pressings. This is a group consisting of almost 40 manufacturing and sales companies all over the world. As a long-term and committed spring innovator, the group continuous to grow with a good profitability, but organically and by acquisitions.

1.2 Research motivation

Tribelt and De Spiraal is a constantly growing company. They have been in this building since 2015 and had enough space at the start. During the years they have grown a lot and their warehouse became more and more occupied. They are planning to purchase many machines in the future, but with the space left in the building and the warehouse this won't be possible. The storage racks in the warehouse are occupied, orders ready for shipment are put in front of the storage racks. Also there is no space for new stock and that's why they put it outside sometimes which is bad for the quality. This means much stock is kept on places where it doesn't belong. Also, the efficiency decreases because they have extra work. If it is not possible to grow, this could cost the company customers and money. If they want to expand there is more capacity needed to store stock, which could mean that an improved layout and a storage policy could help to have a higher capacity. The companies want to grow in the future, this is possible when storage racks in the building are broken down and the stock is moved to the warehouse.

The problem originated especially during 2021, because of the scarcity of raw materials. This caused problems and insecurities in the steel market and in the global logistics, the delivery times increased, and the orders got bigger which also caused a higher safety stock. The problem also occurred because their steel supplier in Germany was hit by the floods, which caused a shut down for the company. On that moment they had to look for other steel suppliers. The price of steel increased a lot. They increased their safety stock and because of the growing demand they needed more stock. Their stock is on this moment very high, because they ordered a lot of steel for storage because of the uncertainties. These uncertainties were caused by Covid-19. There are insights for the stock on this moment, this is visible on two different programs, their ERP system, and their warehouse management system.

To tackle the problem several actions have been taken place. They took action to use the warehouse in a smarter way, make more place for storage, and storage has been created on places that are not intended for it. An attempt was made to delay deliveries and to create storage at the companies that delivered their orders. Stock was also stored at the neighbors. The effects of the problems are the quality of the products and the efficiency of the logistics for the company, which also has a price. On this moment there is no opportunity to grow to satisfy demand, so investing becomes difficult. There are also many storage racks placed in the building next to machines, this space could be used for machines.

1.3 Problem identification

1.3.1 The problem statement

The problem for the companies Tribelt and De Spiraal is that there is limited space for the inventory and for new machines. Stock is placed outside and on places where it doesn't belong. They do have two buildings; one is where production takes places and where stock and ready-made stock is kept at storage racks and cantilever racks. The other building is the warehouse where stock is stored and orders that are ready for shipment are stored. Orders that are ready for shipment, transport boxes, and wooden boxes, that are empty, are right now often stalled before the storage racks. This means stock in storage racks is not directly accessible, which decreases the efficiency of the internal logistics. Stock is also placed outside, which could cause problems for the quality of the material, because the material can be sensible for the weather outside and the processability will become harder. This all will cause a lower efficiency. The materials can be sensible for the weather outside and could rust. The company is future-oriented and a running business which means they want to invest in new machines, but at this moment there is little space for extra machines. They also invest in buying a lot of materials because of the tensed steel market and the fact that they are growing. They already store some of their stock at neighbors, but this also decreases the efficiency of the internal logistics.

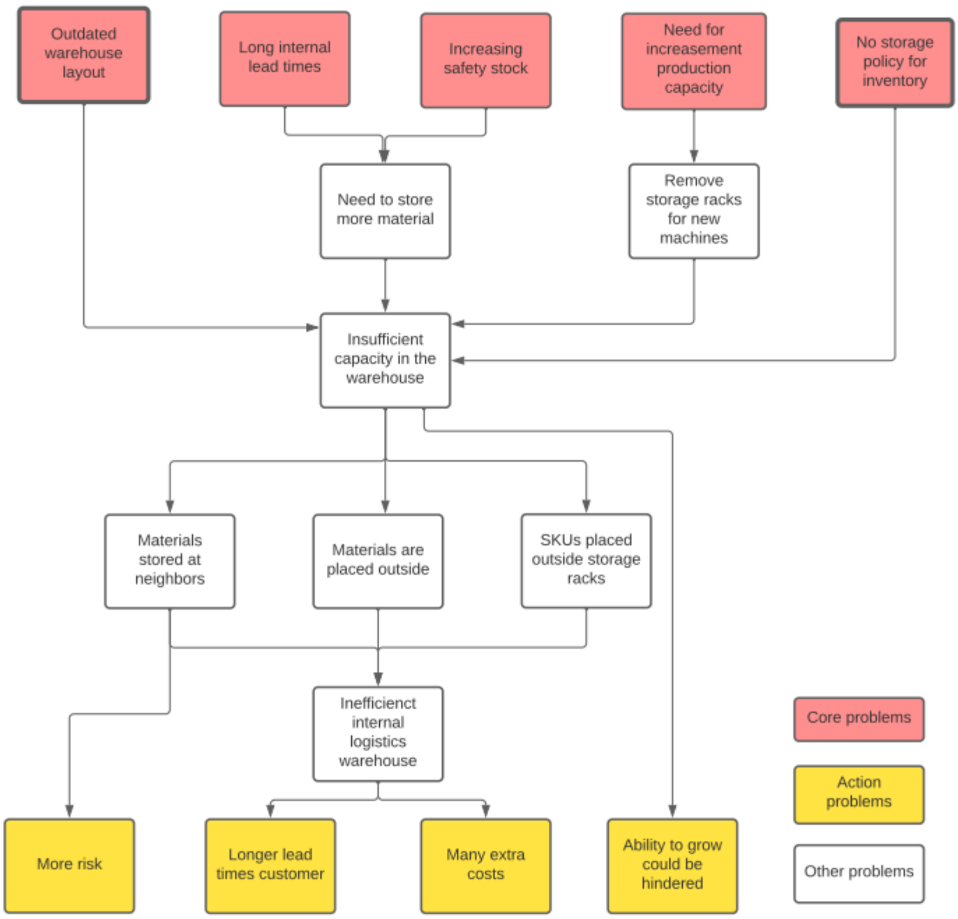

Figure 1: problem cluster

The situation causes a problem for the whole company, especially for the people working in expedition. Expedition takes care of internal and external transport, which means they handle new stock and orders that are ready for shipment. The efficiency for the company is lower due to the problem. In the future the problem could also occur for the people working in production. In the long term it could hinder growth. It could also affect the customers on long term indirect because the efficiency will be processed in sales price. Also, the lead time could increase. Because they store materials at their neighbors, they are taking a risk, because the expensive materials are not insured.

If the problem is not addressed, then there could occur action problems which can be seen in **Error! Reference source not found.**. There is no room for growth and the problems will pile up, which could cause a capacity shortage if the problem is not addressed. The efficiency of the company will go down, as well as dissatisfied employees because the lead time for customers might increase and there will be extra costs. That's why the company would like to expand, but the mother company, Lesjöfors, has the mandate over the company and first wants to see a plan, because it will be very costly to build a new building when this is maybe not even necessary.

The urgency to tackle the problem is high. The efficiency for the materials is a real problem because they are stored outside, outside the storage racks or at neighbors which can be risky because of the insurance. Also new space for machines is limited, which could be expanded by breaking down storage racks in the building. For the future it is important to invest in new machines to place in the factory. For both machines and materials is no place right now. It is important to meet expected demand with the growing trendline going on right now, this won't be possible. The company produces mainly on a make-to-order basis, which means they need enough stock to satisfy demand. This means they have a huge variety of materials because the characteristics and thickness of the wire differs a lot for the products that are produced.

1.3.2 Core problem

The core problems that came out of the problem cluster are marked with red in **Error! Reference source not found.**, namely that there is no storage policy, the outdated warehouse layout, the long internal lead times, the increased safety stock, and the need for increasement production capacity. If you cannot influence something, then it cannot become a core problem (Heerkens & Winden, 2017). The company is growing and wants to expand, this means that the need for production capacity increases and storage racks are broken down for new machines. There is also a need to store more material because the safety stock and the internal lead time increased. The core problems that can be influenced is the layout of the warehouse and the storage policy. These are the two core problems, because much space is left between the warehouse racks, many materials are standing on places where they don't belong and there is currently no right storage policy for the stock. The core problem is not directly measurable, so it must be operationalized. Indicators must be selected to measure the variable. The variable that is connected to the problem is the capacity of the building. The capacity decreases the efficiency of the internal logistics, which is a problem that must be tackled.

1.3.3 Measurement norm and reality

The core problem is that the warehouse layout is outdated and that there is no insight in warehouse management of the warehouse. The norm is smooth product flow and visibility/findability and efficient storage and routing, but the reality is there is no smooth product flow and visibility/findability and no efficient storage and routing. Management wants to solve the fact that they have not enough capacity to store stock and transport boxes. The internal flows of stock and finished orders are currently complex and decreases efficiency. To solve the problem proper item placement can be quite important, by looking at slow and fast movers. The layout of the warehouse must be discussed and chechked if this could be improved to create more capacity.

Currently the capacity is 1178 pallet places and there is approximately 650 meters available for wooden boxes. The reality is that they are not all occupied, because of the accessibility. Putting away materials is currently done on experience, which is not the most efficient.

1.4 Research objective

The research objective is:

- Smooth product flow and visibility/findability
- Efficient storage and routing
- Improving warehouse layout

The goal of this research is to find an improvement in the layout of the warehouse to increase the capacity of warehouse and to improve the storage policy, which currently isn't there. Accessibility must be increased keeping in mind the proper item placement in the layout, assigning the product to the right locations. Coming up with a solution for the company and keep in mind different perspectives, recommendations can be given to improve.

1.5 Research design

For the design of the research, the Managerial Problem-Solving Method, MPSM, is used. The phases of the MPSM are the basis for the problem-solving approach of this research. Each of the phases allows to use different models, techniques, and methods to your hearts content. This lends itself to methods used in project management (Heerkens & van Winden, 2016, p.14). It is a problem-solving method which consists out of seven phases:

1. Defining the problem
2. Formulating the problem
3. Analyzing the problem
4. Formulating (alternative) solutions
5. Choosing a solution
6. Implementing the solution
7. Evaluating the solution

The first two phases are already included in the introduction and the other phases will be conducted during the research.

To solve the core problem of this research, the following research question is formulated:

"How can the capacity of the warehouse of Tribelt and De Spiraal be increased by improving the layout and the storage policy?

By answering this research question, we aim to solve the action problem with the core problem the company is facing an outdated layout and no storage policy. To answer this research question, there are multiple knowledge questions composed.

Phase 1: Analysis current situation

1. **How is the current situation regarding the warehouse configured at De Spiraal and Tribelt?**

1.1 What are the characteristics of the different materials stored at the warehouse?
1.2 What is the current layout?
1.3 What is the current storage policy?
1.4 What is the current capacity of the building?
1.5 How are currently incoming and outgoing goods distributed?
1.6 What is the current performance regarding the SKUs in the warehouse?

Chapter 2 will cover phase 1 of the research, to answer the main knowledge question of phase 1, multiple sub questions have te be answered to analyze the current situation of the company. That's why we will look in this chapter of the characteristics of the different materials that are stored at the warehouse, the current layout, and the current storage policy. Also, the current performing regarding the efficiency/driving distance is important for this research. The data will be collected through data analysis from the systems within the company that are currently used for the inventory. We will also conduct interviews with people on the work floor and at the office who relate to the problem. We will also do observations to observe the problem. Also, a pareto diagram will be made to look at the SKUs that have a high turnover and low turnover.

Phase 2: Literature review

2. **How can the storage policies found in literature be applied this warehouse?**

2.1 How can the layout problem be characterized?
2.2 Which storage methods are there and what trucks can be used?
2.3 Which storage policies are there in the literature?
2.4 Which storage policy is suitable for this case?
2.5 What performance measures are commonly used to optimize?

Chapter 3 will consist out of a systematic literature review. The objective of this chapter is to find a method to cover the core problem. Phase 2 of this research will give an answer to question 2 and gives insights in storage policies for companies. To answer this question multiple sub questions are posed. The sub questions will answer the suitable storage policies, classification for the stock, performance measures to optimize and the different storage methods. Different methods/theories will be discussed in this section to look which method/theory is the best.

Phase 3: Constructing a model based on literature

3. **How can the storage policies and layouts of warehouses found in the literature be applied to this case?**

3.1 How can the different SKUs be classified?
3.2 What elements from the literature can be used and applied for the situation at Tribelt and De Spiraal?
3.3 What key performance indicator(s) (KPIs) should be included in the model and optimized?

In chapter 4 of this research, we will construct models based on the literature, which can be applied to the case of the company. We will look at different models to look which is the most cost-effective and efficient. We will also look at the KPIs which can be applied for the company to see the performance. For this we will look at the previous literature reviews that are performed and use data from the companies to look at the KPIs.

Phase 4: Choose possible solutions

4. **Which solution is the best to increase the capacity and efficiency?**
   4.1 Which layout of the warehouse will increase capacity?
   4.2 Which layout improves the efficiency?
   4.3 Which results can be expected when implementing the chosen solutions?

Chapter 5 will look at the possible solutions for the problem regarding the warehouse of Tribelt and De Spiraal. This means that in this chapter we will come up with a solution regarding the problem.

Phase 5: Implementation solutions and evaluation

5. **How can the obtained strategy be implemented in the company in an effective and efficient way?**

Chapter 6 presents a plan of how the obtained strategy can be implemented at the warehouse. In this chapter we will look at previous results and data and perform a literature review on best presenting the results that are obtained. It is most likely that the renewed strategy cannot be directly applied in the scope of this thesis.

Phase 6: Recommendations and conclusions

6. **What are the recommendations for the company to make?**

Chapter 6 will summarize all the findings of the thesis and give recommendation to the company to make. It will conclude the findings and how to implement the plan.

1.6 Scope and limitations

We will work with different groups of materials, which means that the different stock items will be classified to characteristics. We will also work with stock keeping units, SKUs, which will be one pallet. The pallet is the standard and transport boxes will be compared to the standard. Keeping every detail in mind will become too broad for the scope of this research. There is also many stock and ready-made stock stored at the production floor, this will not be included in the research in a broad sense. There are storage racks and cantilever racks. For the storage racks we can determine how many locations for pallets there are, this is not the case for the cantilever racks, that's why we determined the length of these racks. During the research groups of SKUs will be made, otherwise it will be too broad. The different SKUs will be grouped into A, B and C, which depends on the number of orders of a certain SKU. Based on the ABC classification, the travel distance is calculated. The travel distances are all calculated from Excel files, where there were made layouts based on the improved layouts. The layouts are made in Solid works and the dimensions can differ a little bit from reality, but there are some extra dimensions considered.

1.7 Stakeholders

The stakeholders in this research are the managing director, the operations manager and people working in expedition. The people working in expedition encounter problems when putting the materials on the pallet in the storage racks and getting the pallets out of the storage racks. Now, internal, and external is inefficient and takes a lot of time. The operations manager and the managing director would like to see an improved layout with a storage policy.

1.8 Validity and reliability

Due to the scope some elements will be left out which could decrease the validity of the research a little bit. The reliability will be high, because there will made use of data of the company Tribelt and De Spiraal. The fact that there are many different materials could damage the internal validity. Because the different materials are grouped, but this doesn't mean that they are the same. The travel distance is calculated for the different layouts, this can deviate. The proposed layouts all have different dimensions between the racks, which can also deviate in reality. There are often extra dimensions taken into account.

1.9 Conclusion

The companies Tribelt and De Spiraal would like to increase the capacity of the warehouse. The core problem is that the layout of the warehouse is outdated and does not meet their requirements. The company wants to increase the available pallet places by creating a new design for the layout of the warehouse.

2. Current situation

In this chapter the current situation will be described. In 2.1 the product characteristics and the coils on the pallets are described. 2.2 describes the current layout and dimensions and the racks that are right now used. 2.3 describes the current storage policy and 2.4 describes the current capacity. 2.5 describes the in- and outbound for the companies. 2.6 shows the Pareto-diagrams for Tribelt and De Spiraal.

2.1 Product characteristics

As mentioned in the previous chapter, the company Tribelt and De Spiraal produces springs, conveyor belts, drive wheels and wire products for their customers by processing metal wire and strip metal. The company is an original equipment manufacturer (OEM) and delivers part to other companies. The products vary a lot, there are small products but also very heavy products. The products are made with many different machines. When an order is ready for takeoff to another company, the order is stored in a wooden box and put in the warehouse. There is no storage policy for this, everything is based on experience and being able to know where it stands.

The company has also 4 lean lifts, this is where they store products that are produced and stock them as inventory until a customer buys them, which is called make to stock. But most of the products that customers want are made on a make-to-order basis. Products can be made customized for the customers. Customers sometimes buy products in large quantities, but also in small quantities. Higher quantities are more of the most cost-effective for the customer due to machine set-up times.

Figure 2: Coils on pallets

Most of the products are processed with metal wire, which can be seen on Figure 2. The materials are from steel but have their own specifications and the thickness of the materials also differ. The materials are used to make springs, conveyor belts and wire product. This is done with all kinds of machines. The products that are made with steel wire do vary a lot, from small to large wire products. The conveyor belts can be applied in the process of foods, for the pharmaceutics industry, for the industry. The springs can be used in the automotive industry, mechanical engineering, aviation, household appliances, precision mechanics and are used in diverse everyday applications. Even in bicycle you can find springs.

Because of the huge variety of wire products, the materials that must be stocked, orders that are ready for takeoff and product that are ready that are stocked are there a hundreds of SKUs. For a lot products to make, there are other materials needed. There are also high costly SKUs but there are also low costly SKUs. The material price is rising due to Covid-19 and the war in Ukraine, this means that the materials are more valuable. Figure 3: Springs

Figure 4: Spring Figure 5: Springs

Figure 6: Conveyor belt

and Figure 7: examples of the productsshow some examples of the products the companies produce with the material on hand. There is a huge variety among the different products produced. The figures only show a handful of the products that the companies produce.

Figure 3: Springs *Figure 4: Spring*

Figure 5: Springs

Figure 6: Conveyor belt

Figure 7: examples of the products

Due to the high variation in size, there are many SKUs. There are over a hundred different SKUs, that’s why we will make different classifications in the SKUs. The SKUs will be classified to the number of orders, from high to low for the different SKUs, this means the number of times the truck must go to the warehouse to pick up a pallet.

In the warehouse mainly stock is stored and transport boxes that will be used to transport conveyor belts. There are also a lot of empty transport boxes, these are delivered earlier than expected or could be returned from customers. This means there are transport boxes that are ready and transport boxes that have a belt in it. There is also a classification in the materials, this is based on the materials that have a high throughput and a slow throughput in the warehouse. This classification will be explained in section 4.2.

2.2 Current layout

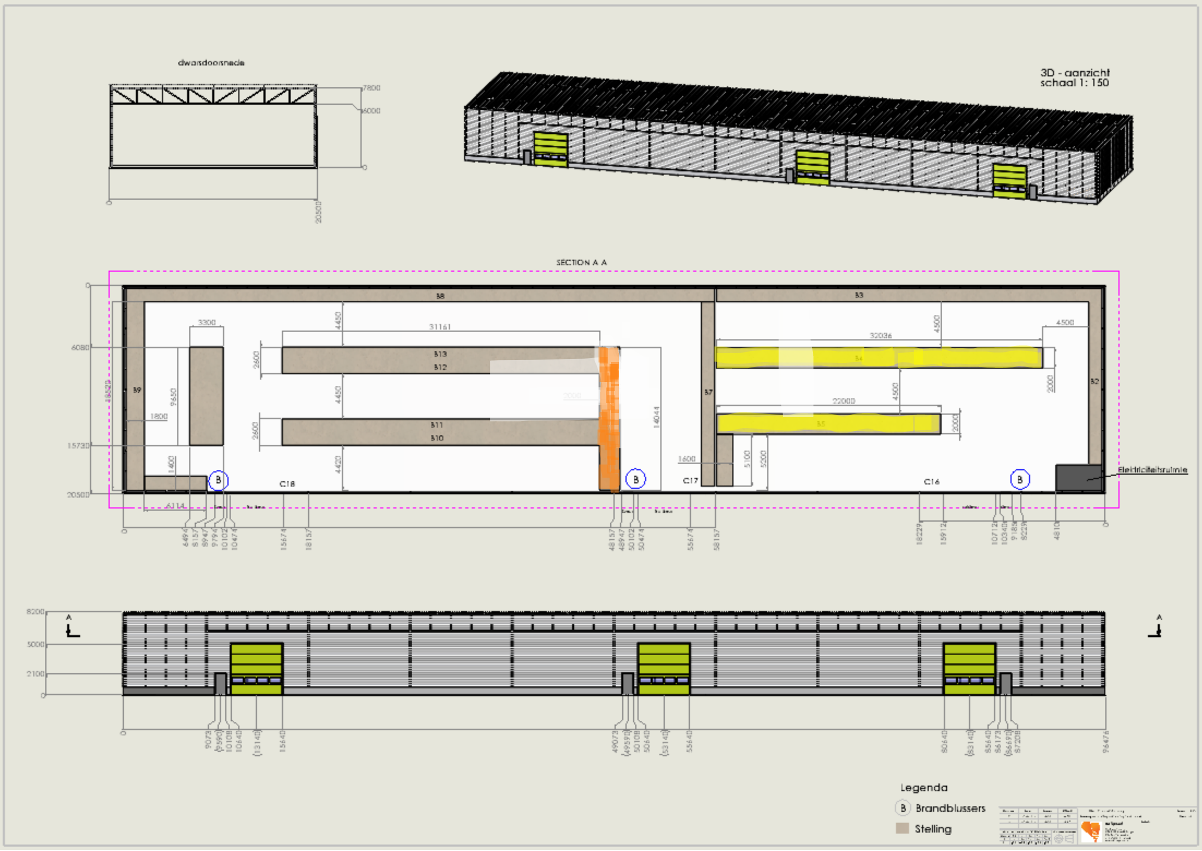

Figure 8

Figure 8shows the current layout of the warehouse for the companies Tribelt and De Spiraal. The yellow marked parts (B4 and B5) in Figure 8shows the cantilever racks. The other brown parts are storage racks that are mainly used to store pallets. During the research the company made a change, B4 no longer consists of cantilever racks but became a single pallet rack and B5 is a double cantilever rack. B10, B11, B12 and B13 are pallet racks. This also counts for B2, B3, B7, B8, B9. The orange part is the part where there are no racks , but you cannot cross the orange part, because it is higher than the rest of the floor. In the warehouse there are two parts, the right side is for Tribelt and the left side for De Spiraal. The production of Tribelt is also right-oriented and the production of De Spiraal is left-oriented.

The warehouse is currently 20.5 meters broad, and the length is 96.476. This means that the total surface is 1977.76 square meters. The height is 7.8 meters, this means the volume is 15426.51 cubic meters. Even though the height is 7.8 meters, the volume cannot fully be utilized due to a construction at the top of the warehouse.

The cantilever racks are used for transport boxes, but this is currently often not the case and transport boxes are stalled before the cantilever racks. Currently, there is a lot of space between the racks, as can be seen in Figure 88, the aisles measure between 4.42 and 4.50 meters. There is a difference between the aisles because of the different racks. In the plant of the company there are also many spots for pallets. This means that this is also functioning for storage of stock.

The company already invested in four lean lifts, these are located in the factory and are used for small products. Incoming stock is heavy and is placed on pallets, which must be stored in the warehouse or in the factory of the company. From the warehouse, they're going to the plant/ factory when necessary. The storage racks in the warehouse can be seen Figure 9, here is where they store mainly pallets and on Figure 10 we can see the cantilever racks where they mainly store transport boxes. The cantilever racks have a depth of 80 centimeters and the pallet racks has a depth of 120 centimeters.

Figure 9; pallet racks

Figure 10; cantilever racks

In Figure 11: layout with (in)efficient places the layout of the warehouse can be seen with the efficient and inefficient places that marked with colors. The inefficient are marked with pink and the efficient places are marked with light green. The dark blue spots indicate the spots which are picked the most by the employees. The figure shows that the most inefficient places are not picked most by employees. These inefficient places indicate especially places where wooden transport boxes are placed for pallets racks or where access is blocked. This means that the travel distance increases, or transport boxes must be moved away to pick up a pallet. The green spots are the efficient places, these places also indicate the places which are picked the most by the employees.

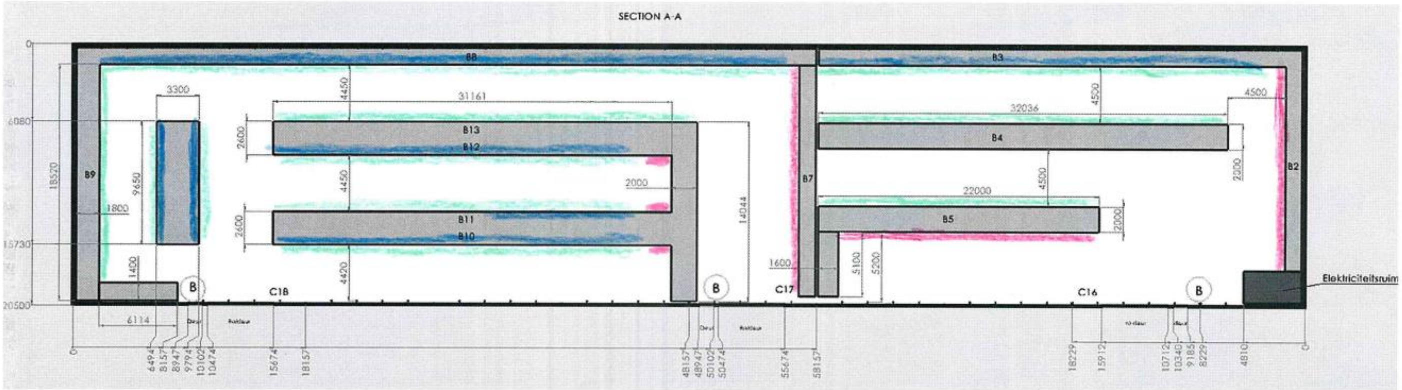

Figure 11: layout with (in)efficient places

2.3 Current storage policy

The warehouse is functioning for the companies Tribelt and De Spiraal, also the warehouse is split up in two parts. The left-hand side is for de Spiraal, and the right-hand side is for Tribelt. When an incoming order arrives, people working in expedition look at the ERP system Ridder with the receipt on the order and print out another inventory receipt for the incoming material. After that the order goes to the production floor, to the racks in the factory or to the warehouse. If there is no location for the order, the order is placed outside, at neighbors or in front of storage racks in the warehouse. There is no system for putting things away, it is just based on experience of expedition people. This means there is no storage policy right now.

The place where the order is located is put in the system called Hänel, so that co-workers can find the location of the material. Also, the weight of the material is reported. Ridder also shows if there is a production order for material that is delivered. When this is the case, the material is often going directly into the factory. There are also many storage racks in the factory, this makes internal logistics easier. They don't make use of fast and slow movers because they find it too complex. Wherever there is space for material to be stored, they will store it if it's useful. When a big order is coming in and there is only space for a part of the order on different locations, then they don't put it away because they think it is inefficient. The order then stays outside, even if there are locations available, because it became too complicated to look after all the materials.

Orders that are ready for takeoff are placed in transport boxes are stored in the warehouse with a receipt and are placed on locations on experience and where space is. These orders are placed in transport boxes of wood. Expedition knows where it is stored, the other employees have no idee and have to look into the system. When employees need to look up a certain product, then you can search for the article number in the warehouse system. There is no logic in the warehouse, only the SKUs that are the same are supposed to be places close to each other. There are cantilever racks to put the transport boxes in, but this costs more time than just put it before the cantilever racks and pile them up. The whole process of putting away orders can be found in Figure 12.

Currently, products are stored fictively in the warehouse system to find the materials back and to put them in the system. These materials are standing on the ground and have to be booked in and out of the system. This is not the case for all of the products, because the Tribelt part is storing it in the system, but the De Spiraal part doesn't store it in the system. Also, many boxes that are identical are not storedin the system, because these are also not stored in the cantilever racks. The current storage policy can be found in Figure 12; storage policy.

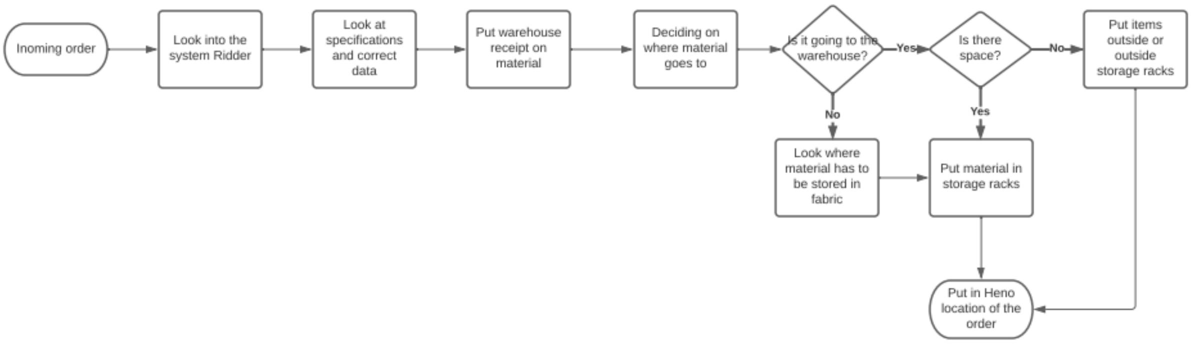

Figure 12; storage policy

2.4 Current capacity

The width of the warehouse is 20.5 meters, and the length of the warehouse is 96.48 meter. The surface of the warehouse is 1977.76 square meters. The height of the warehouse is 8.20 meter, but this height cannot be fully used because of construction work. The space between the aisles is on the left side of the warehouse 4.45 meters and on the right 4.5 meters because the right side has cantilever racks and the left side pallet racks. We make a difference between the cantilever racks and the pallet racks because pallets cannot be stalled at the cantilever racks. We make a difference in this because both function for something else. In **Error! Reference source not found.** numbers B4 and B5 are for the cantilever racks and the rest are storage racks.

In the warehouse there are currently 1257 pallet places available. This is calculated from an excel file from the company. They also do have cantilever racks, these are hard to calculate because it is not one location, so we calculated the number of available meters which is approximately 264 meters. This is where transport boxes can be stored. We also calculated the available meters because the transport boxes differ in height, depth, and width. They already created new pallet places on the right side of the warehouse. A pallet rack has been placed on one of the spots of the cantilever rack to create more pallet places. These concerns (34*4=) 136 new pallet places. So, the new total amount of pallet places is 1257+136 =1393. Before, there were more places for transport boxes, the meters available decreased with (648.43-264=) 384.4 meters.

An EUR pallet is used to store products, the dimensions are 1.20 meter by 0.80 meters and are placed in the storage racks. The pallets are always placed in the length. The company also makes use of transport boxes (**Error! Reference source not found.**) of wood which are meant to be stored in the cantilever racks. The cantilever racks have a depth of 80 cm. The transport boxes do differ a lot in size, because they are customized on the size of the ordered conveyor belts of customers. The transport boxes are customized because this decreases the transportation costs for customers. Transport boxes are stored in the warehouse and cannot be stored outside, because this is not good for the material. Transport boxes that are ready to be picked up for transport are often in the warehouse for multiple days. This is not the intention, but it does happen, the goal is to store at as short as possible in the warehouse. Transport boxes can be seen on Figure 13; pallet
Figure 14; transport box.

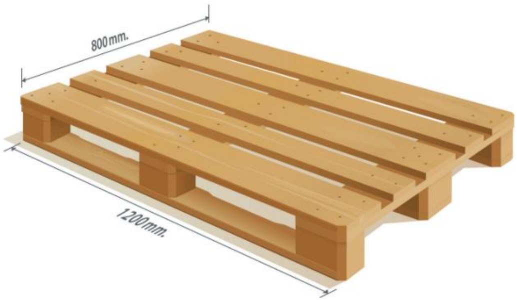

Figure 13; pallet

Figure 14; transport box

On this moment the warehouse makes use of wide aisle also selective pallet racking. Every pallet is accessible at any time and the racking is easy to install and, if necessary, to move. Access is also quick and easy compared with most other type of racking. The disadvantage is in the fact that wider aisles are required to allow the forklift trucks sufficient turning circle. Introducing other trucks could reduce the amount of aisle width required (Richards, 2011). The wide aisles are coming back in the fact that the aisles of the company are between 4.42 and 4.50 meters wide.

Stelling	**Number of pallet places**	**Cantilever racks (meters)**
16	236+136	44*6
17	389	0
18	559	0
Total	1393	264

Table 1: number of pallet places

2.5 Distribution stock

Both Tribelt and De Spiraal have wire in the warehouse as stock. The companies have inbound and outbound depending on demand, seasonality's and supply. If we look at Figure 15; In- and outbound De Spiraal and Figure 16; In- and outbound Tribelt then we see that the inbound of wire is fluctuating a lot, this is also the case for the outbound but this is less the case. The variations causes that sometimes the stock is very high and sometimes not, this causes that the warehouse is sometimes highly occupied.

When a big batch of stock is coming in and it can be stored on one certain location, then the pallets are stored on the floor with each other, because otherwise the pallets are all randomly stored . This causes an efficient spot at that time, which can be there for a long time.

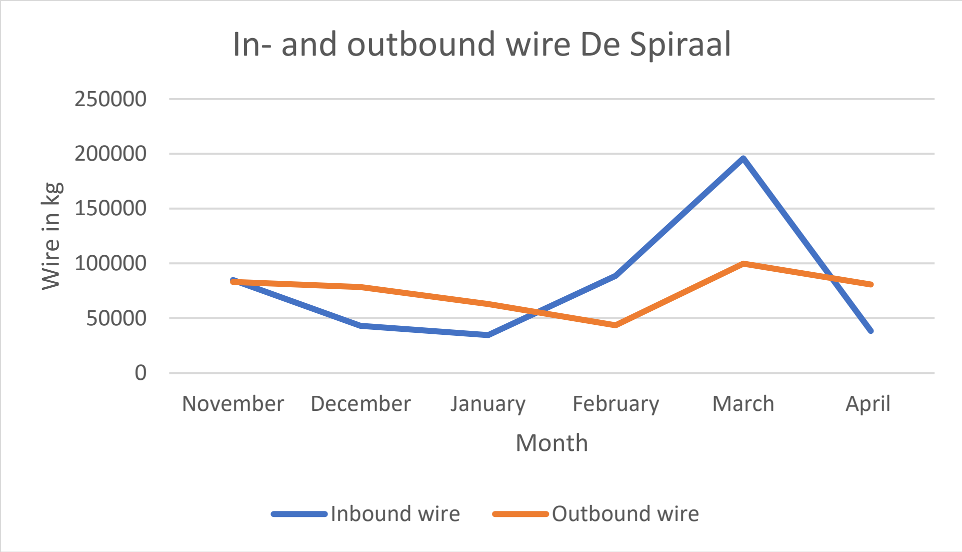

Figure 15; In- and outbound De Spiraal

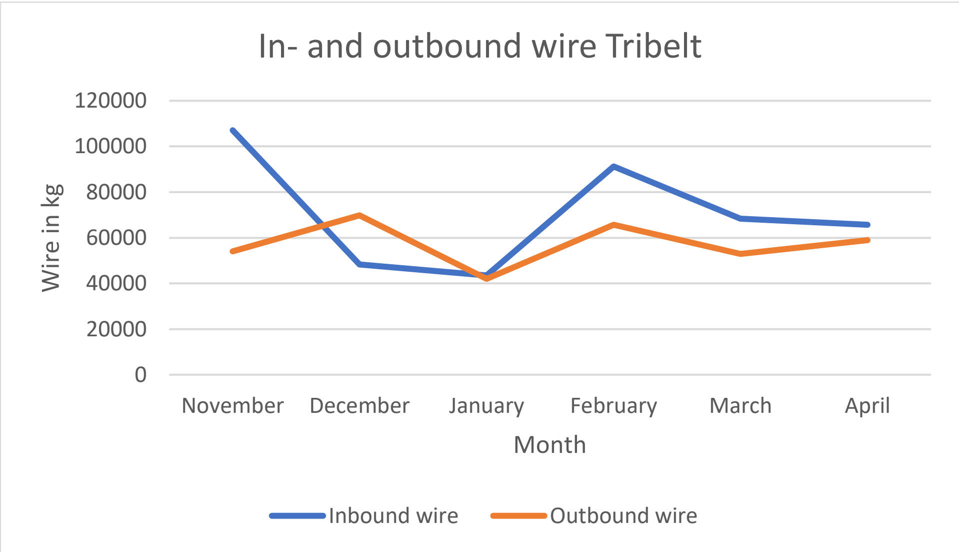

Figure 16; In- and outbound Tribelt

Currently, the biggest problem around is that the transport boxes are blocking required space.. They are also often not stored in the system because they do not have a specific location. Sometimes they are moved multiple times because there are pallets behind them. They are often standing on the floor in front of pallet racks which is not efficient. This causes that the boxes must be moved. The intention is for the transport boxes to arrive as soon as the order is ready, but this is often not the case. Only empty transport boxes are delivered, in these are going conveyor belts that are ready for take-off.

For the in- and outbound activities at the warehouse a forklift truck is used. The aisles are also made to the dimensions of the forklift truck. The aisles are between 4.42 and 4.50 meters wide in the warehouse. This forklift truck has a payload of 2 to 2.5 tons and is used in the warehouse for retrieving and storing pallets. This forklift also must go outside to go to the plant, that's why these forklifts are used. The forklifts that are used are called reach truck. The aisles of the current layout have broad aisles for the reach trucks. The reach truck move pallets and transport boxes. Pallets have the same dimensions; this is not the case for the transport boxes. These boxes have different dimensions, and for this the aisles must be wideenough. Since every pick action consists of a retrieval of only one pallet, the pick policy can be described as single command picking.

This forklift that can be seen on Figure 17; forklift truck needs an aisle of at least 3.852 meters. This means that the aisles need to be at least 3.852 meters when keeping the same forklift. There are also trucks that can operate in smaller aisles, which will be more efficient when increasing the capacity. This will be an investment, but it will outweigh the advantages from increasing the capacity.

Figure 17; forklift truck

2.6 Pareto-diagram

Error! Reference source not found. and **Error! Reference source not found.** show a Pareto-diagram, this shows how picking is distributed over the SKUs. **Error! Reference source not found.** shows that for 80 per cent of the number of receipts, 11 per cent of percentage of the number of SKUs is necessary. This is different for De Spiraal, because for 80 per cent of the number of receipts there are 28 per cent of the SKUs in the warehouse is necessary which can be found in **Error! Reference source not found.**. The Pareto-diagrams show both that a small amount of the SKUs takes care of a large part of the orders.

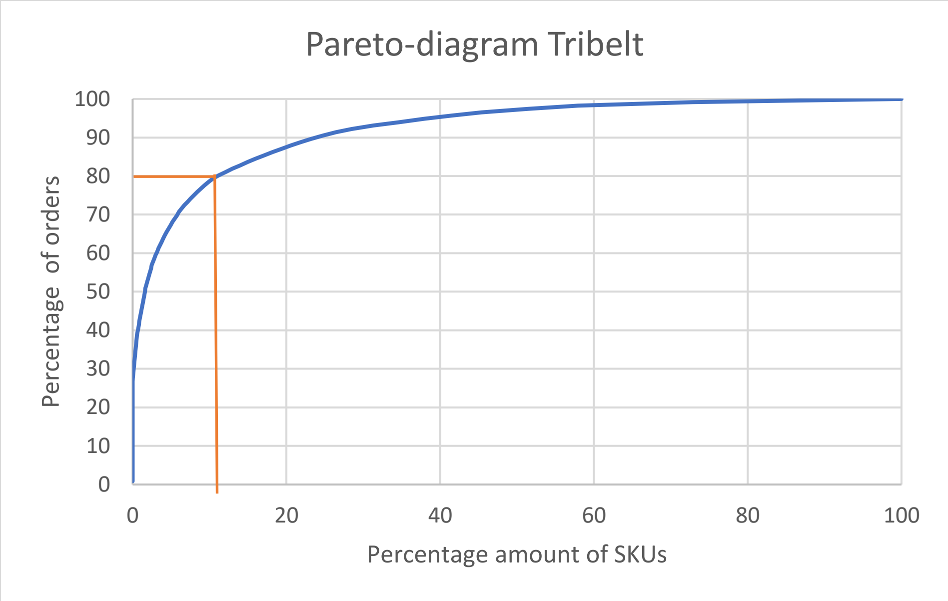

Figure 18: Pareto-diagram Tribelt

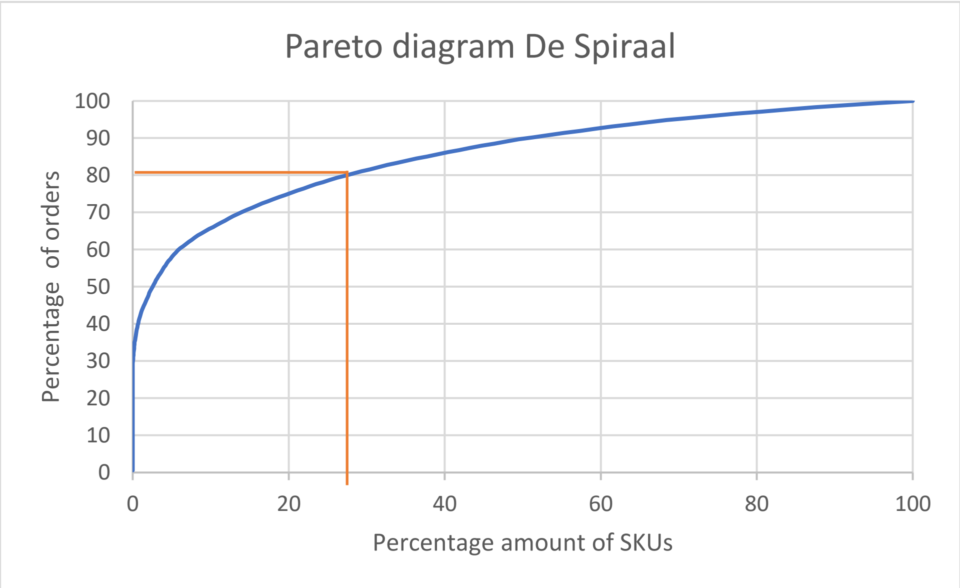

Figure 19: Pareto-diagram De Spiraal

2.7 Conclusion

The layout now consists out of big aisles and the surface of the warehouse is 1977.76 square meters. The current capacity is 1320 pallets, the goal is to increase the capacity. Right now, there are pallet racks and cantilever racks. For the pallets there is no real storage policy, it is just randomly put away. The in- and outbound are fluctuating, which causes that sometimes the warehouse is very full and sometimes not. The Pareto-diagram shows that only 11 and 28 per cent of SKUs in the warehouse cause 80 per cent of the number of receipts.

3. Theoretical framework

This chapter describes the theoretical framework used within this research. A literature study is executed to gain more insight in storage policies and to improve on the layout of the warehouse at Tribelt and De Spiraal. Storage policies deal with item placement and product allocation where we will look for in the literature. You can find in the appendix the search queries for the literature review. During the research we will make use of the Managerial Problem-Solving Method (MPSM) from Heerkens & van Winden (2017).

3.1 Layout warehouse

3.1.1 Warehousing

The main function of a warehouse is storing materials and finished goods. However, a warehouse also has other functions that are also important. The functions of a warehouse are as follows (Frazelle, 2002):

1. being temporary storage area.
2. keeping the supplies needed as a counterbalance and a buffer of variation between production and demand.
3. being the distributor of a company and customer service center to meet the needs of the shortest transport distance and quick response.
4. being a place of production and distribution activities.
5. protecting stored goods from theft, fire, flood, and other weather problems with guaranteed safety and security system.

There are several factors to be considered in determining warehouse layout, including (Frazelle, 2002):

1. Product characteristics
2. Size and weight of the product
3. Load accessibility
4. Inventory control
5. Warehouse dimensions
6. Material handing

Warehouses are a key aspect of modern supply chains and play a vital role in the success, or failure, of businesses today. The operations of warehouses are critical to the provision of high customer service. It is thus imperative to the success of businesses that warehouses are designed so that they can function cost effectively. This is particularly important as warehousing costs are to a large extent determined at the design phase (Baker & Canessa, 2009). High number of product varieties is the main problem that happens in storage areas. The employees tend to have difficulty finding the right products in warehouses quickly. New warehouse layout design may alleviate this problem. Warehouse management is one of the logistics activities that currently occupy the highest cost. Warehouse operation problems relate to the four major functions; receiving, storage, picking and shipping (Patitad et al., 2013). At the companies there is a huge variety of SKUs which makes picking not optimal, they always must look in the system where the SKUs are.

Warehouse management involves location selection, sizing, layout design, administration system design. Location control, delivery, and data record. It is found that there are two types of warehouse management: internal operation system management and layout management. Order picking is a key operation in managing a warehouse efficiently. It presents 65% of the total operations costs of a warehouse. The strategy used to allocate the products influences almost all the warehouse performance and depends strongly on its layout. Storage location assignment problem consists of allocation the product to the different slots in a warehouse, minimizing the handling costs, and maximizing the space utilization. The basic principle is that the high-demand products must be allocated in the slot closer to the input and output (I/O) doors for reducing the total time in handling. Travel time is wasted since it costs labor hours but does not add value. Warehouses must improve their order fulfillment operations through better storage, batching and routing strategies (Patitad et al., 2013).

Each storage location is assigned a unique address. Storage locations are expensive because they represent space with consequent costs of rent, heating and/or air-conditioning. In addition, storage locations are typically within specialized equipment, such as shelving or flow rack, which are a capital cost. These costs turn us to use storage space as efficiently as possible (Bartholdi & Hackman, 2014).

In the case of warehouse optimization, the greater savings potential lies in the areas of inventory control and warehouse management. The increased costs for warehouse management according to Sarudin and Shuib (2015) can be found in Table 2: Costs for warehouse management.

1.	Too much inventory
2.	Incorrect inventory mix
3.	Inventory placed non-optimal locations
4.	Inefficient pick or put away processes
5.	High reliance on paper

Table 2: Costs for warehouse management (based on Sarudin & Shuib, 2015).

3.1.2 Three classical levels

An efficient warehouse layout must be able to maximize the use of space, maximize the use of equipment, maximize the use of labor, maximize accessibility to all items and maximize protection of all items. Inefficient layout will decrease the warehouse utility and performance while increasing the operational costs of the warehouse. The problem is to effectively utilize the total volume of a warehouse and to save material handling equipment and labor costs within the warehouse when the warehouse is subjected to certain inventory storage requirements based on demand and supply and order picking throughputs and flow of the warehouse (Sarudin & Shuib, 2015).

Warehouse managers must deal with three classical levels of decisions which are strategic, tactical, and operational effectively to handle the warehouse management and inventory management problems (Sarudin & Shuib, 2015). These three classical levels can be seen more elaborated in Table 3: Three classical levels of decisions (.

Strategic	Policies and plans for using the resources to fulfill the long-term competitive strategy. 1. Layout of the storage area 2. The storage systems (level of automation and the material handling equipment to retrieve items)
Tactical	Decisions are taken that impact the medium term. 1. Determination of the resource dimensions 2. Storage capacity 3. The size of pick zones
Operational	Concerns daily operations.

	1. Batch information 2. Job assignment

Table 3: Three classical levels of decisions (based on: Sarudin & Suib, 2015)

At the strategic level there are considered decisions that have long term impact, which is mainly high investments. The two main groups used for this are the decisions concerning the selection of the type of warehousing systems and the design of the process flow. The process flow consists of receiving, storage, order picking, and shipment (Mantel et al., 2000).

On the tactical level, medium term decisions are made, based on the outcomes of the strategic decisions. Decisions on tactical level are the dimensions of resources, the determination of the layout and a few organization issues, these decisions have a lower impact (Mantel et al., 2000).

At the operational level, processes must be carried out within the constraint by the strategic and tactical decisions made at the higher levels but can be analyzed independently. The main decisions at this level concern assignment and control problems of people and equipment. Decisions concerning the storage process at the operational level are according to Mantel et al. (2000):

- The assignment of replenishment tasks to personnel
- The allocation of incoming products to free storage locations, according to the storage concept determined at the tactical level
- Decisions concerning the order picking process

3.1.3 Layout design

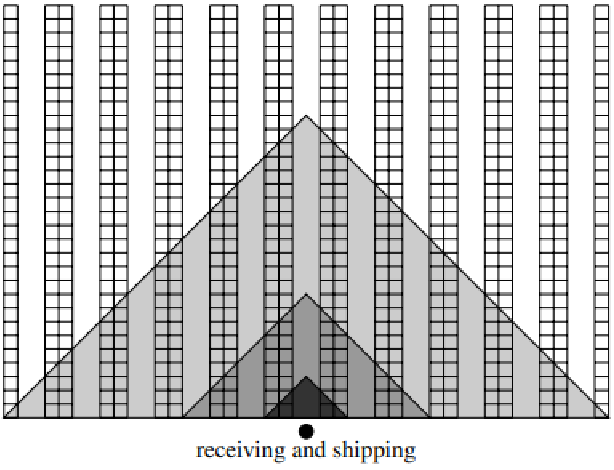

Figure 11: U-flow configuration (Source: Bartholdi & Hackman, 2014)

In Figure 11: U-flow configuration we can see the U-flow configuration. Receiving and shipping are located on the same side of the warehouse. In this configuration the most convenient locations are still more convenient, and less convenient locations are worse. This configuration is appropriate when product movement has strong ABC skew. It provides dock flexibility for both shipping and receiving. It permits more efficient use of forklifts and minimizes truck apron and roadway. It also allows expansion along the other three sides of the warehouse (Bartholdi & Hackman, 2014). At Tribelt and De Spiraal receiving, and shipping is also located on the same side of the warehouse. It has even 3 openings for input and output. This is currently not used efficient, because of the layout.

Determining the aisle criteria and the dimensions and deciding the product allocation are the steps that must be carried out in designing the warehouse layout. The decision on aisle width is one of the material handling equipment decisions. This is due to the type of lift trucks or equipment used will be based on the width of aisle. There are three types of aisle designs which are known as wide aisle, narrow aisle, and very narrow aisle (Sarudin & Shuib, 2015).

Aisles provide accessibility, we prefer to reduce aisle space to the minimum necessary to provide adequate accessibility. For this the aisles must be at least wide enough for a forklift to insert or extract a pallet. By storing product in lanes, additional pallet positions can share the same aisle space and so amortize that cost. The depth of lanes is decided by looking at the effective utilization of space. With the single-deep layout the pallets are directly accessible, which means that they are available for reassignment as soon as te current pallet is shipped out. With double-deep layout this is not possible. The pallets that are directly accessible are not available for reuse until the interior pallet location in the same lane becomes available. Deeper lanes produce more pallet storage locations, but they are of diminishing value (Bartholdi & Hackman, 2014). Right now, the pallets are all directly accessible from one side. The aisles are very width, which can be reduced.

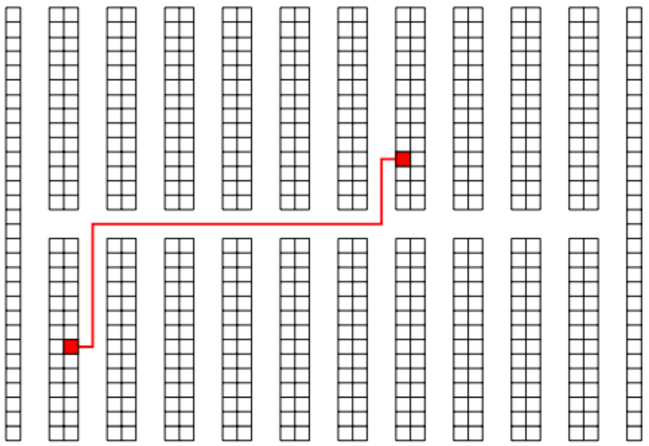

Figure 20: cross aisles (source: Bartholdi & Hackman, 2014)

To reduce travel between storage and receiving/shipping, it is generally preferable to orient aisles so that they run parallel with the direction of material flow (Bartholdi & Hackman, p.67, 2014). Sometimes it is advantageous to travel directly from putting away one pallet to retrieving another one as can be seen in Figure 20: cross aisles (source: Bartholdi & Hackman, 2014).

The disadvantage of cross aisles are the costs in that more floorspace is required for the same number of pallet locations, and o additional travel is reduced. If receiving and shipping are located on opposite sides of the cross-aisle, then every location is made slightly less convenient because the cross-aisle once.

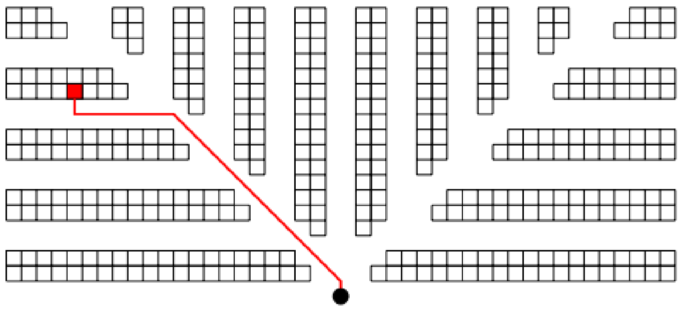

Figure 21: Angled aisles (source: Bartholdi & Hackman, 2014)

Most warehouses have parallel aisles aligned with the receiving and shipping docks, but this does not always have to be the case. Travel times can be reduced by up to 20% by reorienting some aisles and including some angled, cross-aisles which can be seen in Figure 21: Angled aisles (source: Bartholdi & Hackman, 2014), which is also called a *fishbone* layout. This layout allows more direct travel between storage and a central location of receiving and shipping (Bartholdi & Hackman, 2014).

The disadvantages here are that the total warehouse must be a little bigger to compensate for the space lost to the additional aisles; but this is more than made up for the efficiency of more direct travel to or from a centralized point of receiving and shipping. If a forklift finish putting away a pallet and then must retrieve another, the orientation of the aisles of the fishbone arrangement may not help at all, and indeed may be an impediment. This seems to make up by the direct travel to and from the central dispatch point (Bartholdi & Hackman, 2014).

One of the ways of to increase warehouse capacity without doing any expansion is by increasing the storage space utilization in the warehouse. The other one is by doing re-layout to minimize the aisle area that still considers the aisle requirement area (Heragu et al., 2005). A suitable arrangement and layout can considerably increase the storage capacity and operation capacity of the warehouse, which in turn can significantly reduce the storage operation costs. Problems that occur in warehouses are a long handling distance, low space utilization, nonoptimized paths, and disordered placement of goods (Hu & Chuang, 2021). These problems result in a long time being spent in searching for goods and a high probability of picking the wrong order, which affects the delivery efficiency to a large extent (Hu & Chuang, p. 3, 2021).

3.2 Storage methods and trucks

In this part the different storage methods in a warehouse will be discussed and after that the different trucks that can be used in a warehouse will be explained. The different trucks all have other aisle widths which can be important for the new layouts.

Floor/bulk storage

When goods are of a low value with very few SKUs, the use of the floor area for storage and picking is totally acceptable. The disadvantage is the low utilization of the cubic capacity of the building (Richards, 2014). This also the case for the warehouse where the employees stack the transport boxes, because of the lack of space. This is sometimes not done efficiently because the stockpiling does not consist of the same boxes.

Standard or wide (>3.5-4m) and narrow aisle (≥2.5m) pallet racking
Wide aisle racking is used in conjunction with counterbalance truck or reach truck and narrow aisle with reach trucks and very narrow aisle racking with very narrow aisle trucks, articulated forklift trucks and cranes. It is more difficult to pick if the locations are 1200 mm deep. There are the potential issue of truck and people operating in the same aisle at the same time (Richards, 2014). The warehouse at Tribelt and De Spiraal is not that busy, so operating in the same aisle will have a very small chance employees will be hindered.

Very narrow aisle pallet racking (≥1.6-1.8m) meters
This racking can be utilized for the storage of reserve pallets and for pick operations. The issue is the use of rail guided narrow aisle trucks which preclude the use of pallet trucks or pallet jacks to move pallets in and out of the pick locations within the racking. This makes picking more difficult and less productive. The use of automatic cranes in very narrow aisle racked areas can pick full-pallet, single SKUs (Richards, 2014).

Automated storage and retrieval systems (AS/RS)
This system utilized fixed path cranes to collect pallets at the front of the racking system and transport them to empty locations within the racking. The system collects a full pallet from the racking and deposits it at the front of the aisle prior to collecting another pallet to improve productivity and be more efficient. The crane can travel horizontally and vertically simultaneously, thus reducing travel time between pick up and put down (Richards, 2014).

Counterbalance forklift trucks (CBT)
There are multiple types of trucks, one of them is a counterbalance forklift truck (CBT). They are fast flexible and versatile; the disadvantage is that it must approach the pallet with a 90 degrees square. The turning circle of the truck determines the minimum aisle width. CBTs can carry palletized goods to and from racks up to 7 meters high and require aisles of 3.5 meters or more in width (Richards, 2014).

Reach trucks
These are used for working within narrower aisles. They carry the load within the wheelbase and can work in aisles of around 2.7 meters which is most 3 meters. They can operate in single and double-deep racking environments (Richards, 2014).

Narrow aisle or turret trucks (VNA)
These trucks are around 1.6 meters width and operate with little more aisle space than their own width. These trucks can add storage capacity but there are some disadvantages. The disadvantages are that large transfer gangways at both end of each aisle are required to allow the truck to switch aisles. With these trucks there are some safety issues, but this is not applicable to the warehouse in this case (Richards, 2014).

Articulated forklift trucks
These trucks have overcome several issues, including the flexibility of being able to operate the same forklift truck inside and outside the warehouse. Some people find them hard to drive. They can operate in small aisles (Richards, 2014).

Pallet storage
There are multiple ways to store pallets in according to Bartholdi & Hackman (2014):

- Selective rack or single-deep rack: stored pallets one deep. Each pallet is independently accessible, and son any SKU can be retrieved from any pallet location at any level of the rack. This requires aisle space to access the pallets.
- Double-deep rack: consists of two single-deep racks placed one behind the other, and so pallets are stored two deep. Each 2-deep is independently accessible, so that any SKU can be stored in any lane at any level of the rack. Each lane is filled with a single SKU to avoid double-handling. The disadvantages are that some pallet locations will be unoccupied and that more work is required to store and retrieve product. Deep lanes have the advantage of requiring fewer aisles to access the pallets, which means that the warehouse can hold more product (Bartholdi & Hackman, 2014).
- Push-back rack: each lane is independently accessible by pulling out the racks. It is an extension of double deep racking, but it does take time to pick up.
- Drive-In or drive-through rack: allows a lift truck to drive within the rack frame to access the interior loads, but to avoid double-handling, all the levels of each lane must be devoted to a single SKU. Put-away and retrieving pallets is performed from the same aisle. Pallets enter the lane at one end and leave from the other end, to move according to the FIFO policy. This will not be optimal in the case of Tribelt and De Spiraal because they have many SKUs.
- Pallet flow rack: this facilitates high-throughput facilities because it is deep lane rack in which the shelving is slanted and lines with rollers, so that when a pallet is removed, gravity pulls the remainder to the front. This will not be optimal in this case, because the SKUs have fluctuations in demand.

Design is all about trade-offs between speed, travel distances, space utilization, handling, access, safety, risk, and cost. In addition to this space, we need to add working and travel space around the pallets. This space will be determined by the type of forklift or pallet track used to unload and load the vehicles. There are many different types of storage and the kind of racks that will be used. The truck that will be used to operate in the warehouse depends on the aisle width. Changing the aisle width could mean that a new truck must be purchased.

3.3 Storage policies

According to Koster et al. there are five frequently used types of storage assignment: random storage, closest open location storage, dedicated storage, full turnover storage, and class-based storage. In **Error! Reference source not found.** we discuss the five frequently used types.

	Meaning	**Advantages and disadvantages**
Random storage	Every incoming pallet is assigned a location in the warehouse that is selected randomly from all eligible empty locations with equal probability	Advantage: high space utilization (or low space requirement) Disadvantage: increases travel distance and will only work in a computer-controlled environment
Closest open location storage	Order pickers can choose the location for storage themselves	Advantage: first empty location encountered by the employee will be used to store the pallets Disadvantage: racks are full around the depot and gradually emptier towards the back (if excess capacity)

Dedicated storage	Each product will be stored at a fixed location	Advantage: order pickers become familiar with product locations Disadvantage: a location is reserved even for products that are out of stock and for every product sufficient space must be reserved such that the space utilization is lowest among all storage policies (low space utilization)
Full-turnover storage	Distributes products over the storage area according to their turnover	Advantage: easy to implement combined with dedicated storage Disadvantage: demand rates vary constantly, and the product assortment changes frequently, which could mean a lot of reshuffling of the stock, and you need much data
Class based storage	Group products into classes in such a way that the fastest moving class contains only about 15% of the products stored but contributes to about 85% of the turnover. Each class is then assigned to a dedicated area of the warehouse and storage within an area is random	Advantage: easier to implement than full-turnover storage, normally three classes which are determined by COI or pick volume, fast-moving items can be stored close to the depot and simultaneously the flexibility and low storage space requirements Disadvantage: full-turnover storage outperforms class-based storage regarding to travel distance, class-based storage requires more rack space than randomized storage

Table 4: Main methods of product assignment

We prefer that SKUs with a lot of movement per storage location be stored in the best location. This are the SKUs that generate the most frequent visits per storage location. In steady state, during a fixed interval of time, the average visits per storage location is defined as $\frac{number\ of\ units\ shipped}{number\ of\ units\ in\ storage}$ (Bartholdi & Hackman, 2014). This shows which SKUs have the highest movements and must be placed in the proper locations. This storage policy can be proven to be optimal for single command picking, which is the case in our warehouse. This means that orders are fulfilled by manually picking each item directly from a storage place.

3.4 Suitable storage methods

There are two main strategies used in storing product. These are shared storage and dedicated storage. Dedicated storage means that every location is reserved for an assigned product and only that product may be stored there. Workers can learn the layout because of the locations of the products don’t change. The problem is that dedicated storage does not use space efficiently, because every replenishment cycle of each product is different. The more storage locations over which a product is distributed, the less product in each location, and so the sooner one of those locations is emptied and the sooner that space is recycled (Bartholdi & Hackman, 2014).

The other strategy is shared storage, here a product is assigned to more than one storage location. When a location becomes empty, it could be reassigned to a different product. This space can be filled again, rather than waiting until the original product is replenished. The utilization is higher when shared storage is used because the storage location is faster recycled. The disadvantage is that workers cannot learn and so must be directed to locations by a warehouse management system. Another disadvantage is that it becomes more time-consuming to put away newly received product because it must be taken to more locations (Bartholdi & Hackman, 2014).

An inefficient layout of a warehouse can have a negative effect on business. It can decrease efficiency, productivity, aggravate inventory control issues, can cause higher costs of shipping. Properly utilized warehouse will keep overhead costs to a minimum and increase productivity. The ABC classification was used for inventory materials. This is a mix of shared and dedicated storage. The focus in on reducing the distance of fork-lifters that need to drive, where ‘A’ is the most important. As a result, increase productivity and reduce total costs. Based on the ABC analysis, A is designed for high-rotation material, B for medium-rotation material and C for the least rotation material. The put away strategy needs to be changed for material from one batch (Chramcov, Jemelka, & Kriz, 2016). A is the most important, with 20 per cent of products producing 80 per cent of sales, ‘B’ is of medium importance with 35 per cent of items producing 15 per cent of sales, and the remaining 45 per cent being ‘C’ items producing only 5 per cent of sales.

It is important to know what SKUs matter, this can be done by ranking the SKUs by various criteria. We will look at the efficient warehouse operations and not to euro-volume. We want to see the extent each SKU consumes resources such as labor and space. First look at which SKUs accounted for the most cases moving through the warehouse. It might reveal what is flowing in greatest quantity along a conveyor in the warehouse (Bartholdi & Hackman, 2014).

3.5 Performance measures

A warehouse performance measurement is a method to measure activity performance, program or service which is provided by a warehouse. Performance measurement system as the sets of metrics used to quantify both the efficiency and effectiveness of action. Performance measurement can be divided in 4 categories: input, output, efficiency, and effectiveness (Helia et al., 2018).

Activities to measure warehouse performance are receiving, put away, storage, order picking and shipping. To measure those activities, make use of financial parameters, the productivity, utilization, quality, and cycle time (Helia et al., 2018). According to Helia et al., the KPI for receiving is productivity (Receipt per man-hour), KPI for put away is cycle time (put away cycle time), KPI for storage is utilization (%location and cube occupied), KPI for order picking is cycle time (order picking cycle time) and KPI for shipping is productivity (order prepared for shipment per man-hour).

Order picking is the process by which products are retrieved from storage to satisfy customer demand. We can roughly distinguish three components in the time required to pick an order: (i) moving between items; (ii) picking the items; and (iii) remaining activities. Most efforts to improve the operational efficiency of order picking can be categorized into one of three groups of operating policies: (i) routing; (ii) batching; and (iii) storage assignment. Each of these approaches generally focuses on reducing travel times since these are the easiest factors tin influence. (Roodbergen & Vis, 2006).

One of the performance measures for a warehouse is warehouse area utilization, which measures the cubic capacity of the warehouse. Alternatively, we can also measure the number of pallet locations utilized against the total possible locations. The calculation is: (Space used x 100) / space available. This calculation can give the pallet spaces that are occupied.

Facility layout problem (FLP) deals with arranging various facilities of a manufacturer, plant, company, or organization by considering the minimization of total costs. A well-designed facility significantly increases throughput, overall productivity, and efficiency (Hu & Chuang, 2021).

Systematic layout planning (SLP) was proposed by Richard Muther in 1961 and has been widely used in the layout design of factory and workshop equipment. This is a type of planning and design method based on the analysis of logistics and non-logistics relationships between operation units or functional areas. It adopts a set of strong expressions of legend symbols and concise tables and helps solve the layout design problems of factory and work-ship equipment through a series of clear design procedures.

According to Richard Muther there are four phases of ‘Systematic Layout Planning” (SLP). These four phases can be found in Figure 10: SLP.

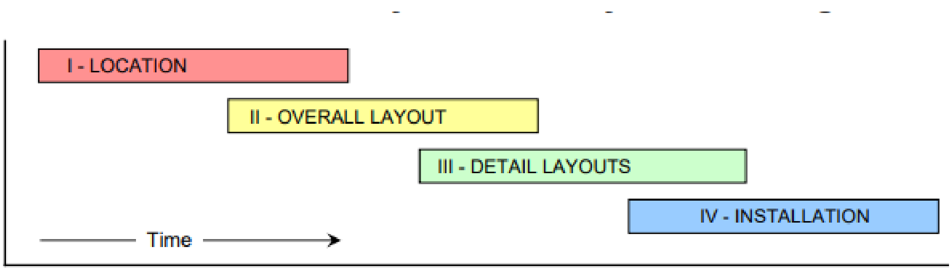

Figure 10: SLP (Muther, 1961)

In phase one the location is established of the to be planned. This is already planned in this case. Also, the available space must be determined and the surrounding influences. The available space is also known. Phase two is about the arrangement of activity-areas and departments, also defining the main aisles. In phase three the arrangement of specific machinery and equipment, ready to install is planned. In phase four the drawing and specifications are prepared: obtain and install equipment; train workers; follow through. Phases 2 and 3 are the planning phases, because phases I and IV are often performed by others. The systematic layout planning is mainly applied to a plant’s layout but can also be applied to layout warehouses (Muther, 2014). To know what it’s the best layout, we could compare multiple layouts.

Facility layout problem: it concerns the decision of where to locate various departments (receiving, picking, storage, sorting, and shipping, etc.). The common objective is minimizing the handling cost, which in many cases is represented by a linear function of the travel distance.

Each time a pallet is stored at a particular location, there is variable labor cost incurred: the travel from receiving dock to location; and, later, travel from location to shipping dock. With each location i there is a labor cost incurred which is proportional to the distance d_i. By storing the pallets on convenient locations, we can ensure that the most frequently visited locations are those of greatest convenience (smallest total travel) by minimizing the formula:

$$\sum_i d_i n_i.$$

3.6 Conclusions

It is imperative to the success of businesses that warehouses are designed so that they can function cost effectively. The strategy used to allocate the products influences almost all the warehouse performance and depends strongly on its layout. The basic principle is that the high-demand products must be allocated in the slot closer to the input and output (I/O) doors for reducing the total time in handling.

In the warehouse there is a u-flow configuration, which mean that receiving and shipping are on the same side of the warehouse. Aisles provide accessibility, to reduce aisle space to the minimum necessary to provide adequate accessibility. Double-deep layout means the pallets are not always directly accessible, but it provides more pallet places with the same aisle. Cross aisles mean that the aisles run parallel with the direction of material flow. One way of increasing the warehouse capacity without doing any expansion is by increasing the storage space utilization in the warehouse. There are trucks that can operate in small aisles.

A useful storage policy is the ABC classification. A is designed for high-rotation material, B for medium-rotation material and C for the least rotation material. Different KPI’s that can be used are the travel distance, the travel time, accessibility, and the amount of pallet places.

4. Apply theory to case

In this chapter the literature found is applied to the case from Tribelt and De Spiraal. Section 4.1 gives an overview of the classification of ABC for Tribelt and De Spiraal. First, we classify the different SKUs into A, B, C and non-moving/obsoletes. Section 4.1 also provides a diagram with the movement right now. Section 4.2 gives an overview of the different improved layouts. Section 4.3 shows an overview of the improved KPIs which is based on accessibility, pallet places, travel distance. The travel distance is worked out in Excel files, where layouts has been made based on the designed layouts.

4.1 Movements SKUs

All the materials with their article codes are classified into different SKUs, from picked most to least picked. In total there are 295 SKUs which are classified to the number of receipts, these are SKUs that occupy the warehouse. This can be found in the excel file 'Copy of materialen magazijn goed', where for Tribelt and De Spiraal there is made a distinction in the number of orders, this distinction can be found in Table 5: Classification by the number of receipts. Table 5 provides a distinction where SKU A is the most picked and the number of receipts is from 51 to 70, for B this is from 11 to 50, and for C this is from 0 to 10. The warehouse is functioning for Tribelt and De Spiraal. The article codes that start with a 3 are mostly from Tribelt and the article codes that start with a 1 are mostly from De Spiraal. The warehouse is across from the plant of both companies. The right side is more located to Tribelt and the left side to De Spiraal. This means that pallets with material from Tribelt that are located on the left side of the warehouse, will have a longer travel distance. The SKUs from Tribelt are located on both sides of the warehouse, this is not the case for De Spiraal, these are mostly located on the left side.

The SKUs are classified to the number of receipts that were made during the last 365 days from the 13th of June onto last year. They are classified into receipts because that is approximately the number of times the pallet must be picked. There has been made a classification between Tribelt and De Spiraal. The material codes can be found in Table 5: Classification by the number of receipts in the Appendix, here the SKUs can be found that belong to A, B and C, according to the ABC classification. The ones that are ordered 0 times are also included because these SKUs also occupy pallet places, and these are also retrieved or put-away.

A	51-70
B	11-50
C	0-10

Table 5: Classification by the number of receipts

There are three entrances on one side of the warehouse, where both in- and output is being processed. On the layout (see Figure 22, down under) there are spots that are named C16, C17, C18, this is where the materials are booked in and out in the warehouse management system (WMS). C16 stands for all the materials placed in rack 16, so when a pallet is picked up the driver has to go to C16 to book the material out, this also applies to materials placed in racks 17 and 18. This means that when a new pallet is placed on the left side of Figure 22: Spaghetti diagram May, in rack 17, the employee has to go to the middle of the warehouse, to book the material in the WMS. This means extra travel time, which is inefficient.

Figure 22: Spaghetti diagram May shows the movement of pallets in the month May, the thickness of the line indicates the number of movements. The line also has a number which shows the exact number of movements. Some lines are very thick, and some are very thin. Some places that have longer travel times are indicated by a higher number than the places that have short travel time. This is not efficient, because this means longer travel distances.

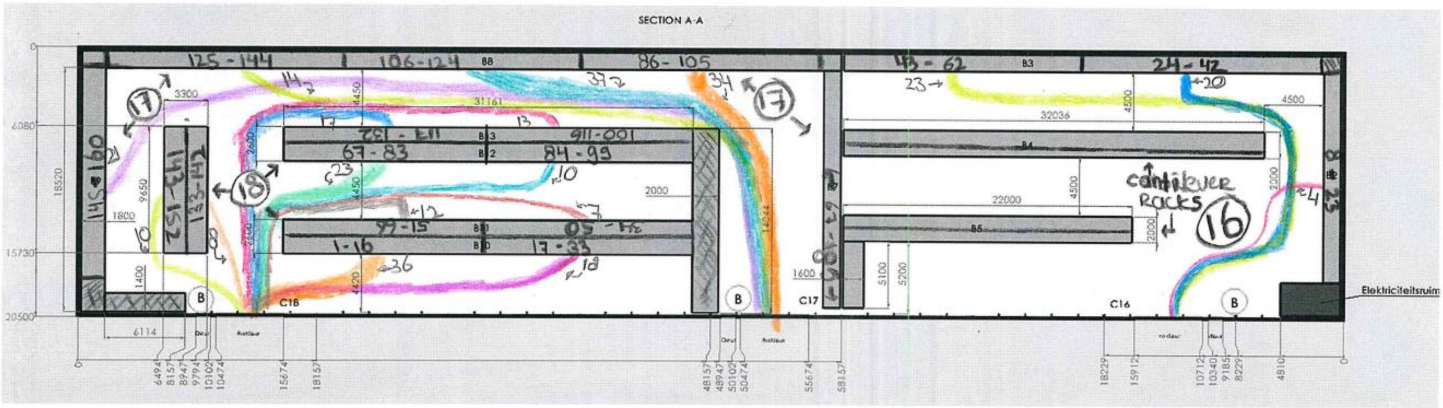

Figure 22: Spaghetti diagram May 2022

4.2 Creating layout alternatives

4.2.1 Towards improved layouts

In this section we construct four alternative layouts. These improved layouts are made in Solid works and are further worked out in Excel to improve the travel distance and travel time that is right now made by the employees. In Solid works there is worked with the pallet width of the racks which also applies now. Figure 23; 3 pallet width

Figure 24; 4 pallet width are showing the pallet width which is 3 and 4 pallet places. The width of 28, which is 2.80 meters is 3 pallets width and the width 37 which is 3.70 meters is 4 pallets width. Working with smaller dimensions would made it very complicated, that's why we choose here is to work with this dimension of the racks.

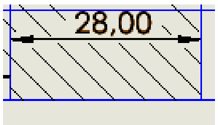

Figure 23; 3 pallet width

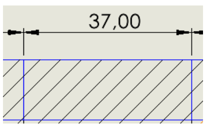

Figure 24; 4 pallet width

The stacking height of the pallets is 4 or 5. This is because the current layout already has different heights of 4 and 5, so the layout that is based on the current situation keeps the same height. Also, for some layouts the height is the mean, which is 4.5, this counts for the layout with small aisles. For all the layouts, the entrance and exit are on the same place as the current situation. Also, the dimensions of the warehouse are the same and extra dimensions are taken into account. Summarizing, we propose the following four alternative layouts:

1) Layout 1: Layout based on current situation. Here we maintain the horizontal aisle structure
2) Layout 2: Layout based on small aisles. Here we change the aisle orientation from horizontal to vertical. Moreover, we reduce the aisle width.
3) Layout 3: Layout based on mobile racking. Here the aisle orientation at the left part is horizontal. However, now the racks are moveable.
4) Layout 4: Layout with push back racks. Here the vertical sides are push back racks, the horizontal side is a double rack, and the other racks are normal racks. The push back racks are only accessible from one side.
5) Layout 5: Layout with an AS/RS. Here the aisle orientation at the left part is horizontal. However, now the racks are fully automated in terms of an automatic storage and retrieval system (AS/RS)

4.2.2 Layout 1: Layout based on current situation

In order to improve the current situation, we added another rack to one of the already existing racks to the side of the warehouse. The space needed is 1.3 meters. This means that the aisle will be 3.150. There are forklift trucks that can operate in this space, this is not possible with the truck the warehouse is currently using. The forklift truck that is necessarily must reach to pallets in the second rack, behind the first one. This means that another forklift truck must be purchased. The aisles right now are very broad and can be reduced. The aisles right now are most around 4.42 and 4.50 meters. Looking at the literature from Bartholdi and Hackman (2014) there are trucks that can operate in small aisles. The forklift truck must lift around 600 kg which means it needs an aisle of around 3.1 meter. In the layouts there are aisles of 3.15 meters. There are also extra dimensions at the bottom of the layout for the transport boxes. There is also another rack added to another rack that is already existing which also creates 132 new pallet places.

Compared to the current layout, the obstructions in the middle are deleted which makes all the pallet places more accessible. Incidentally, this also applies to the other three proposed layouts. Figure 25: layout based on current situationshows the layout that we obtain in this way. We call it: layout based on the current situation. The lines denote the pallets places. If the lines are labeled 37, then there are 4 pallet places width, when the length is 28 then there are 3 pallet places width. The height of the pallets is commonly 4, only for the left and right side it is 5, which will be included in the calculation. The blocks that don’t have lines in them represent the spots for transport boxes. Right now, there are cantilever racks for the transport boxes, but these aren’t used by the employees working in expedition. Therefore, there are created more pallet places where they can be put in. Also, the space without the lines represents a place to store the transport boxes, this might be in pallet racks, or the choice could be to remove all racks and just put them on the floor. Because this is also right now the case and is most efficient for the employees. The transport boxes can be stored more in the pallet racks with this layout because there are created many more pallet places.

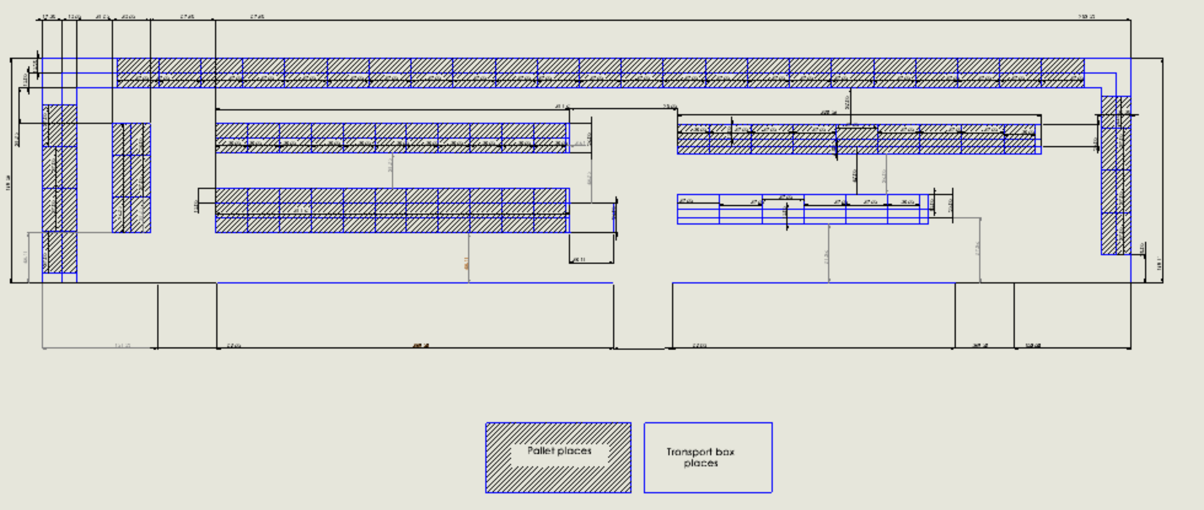

Figure 25: layout based on current situation

Figure 27; pallet rack with cove for truck7 shows some extra space for the truck to stand. This could be implemented to the double racks, then there is some extra space to pick up pallets that are high. This is not necessary, since there exist reach trucks that can operate in small aisles and reach out for the double racks. Figure 26; reach trucks for double deep pallet racking show trucks that can perform in small aisles and can operate in small aisles with double deep racks. The pallets can be very heavy because there are heavy materials on the pallets. In calculating the pallet places, there is no extra space taken into account for the truck to stand at the pallet racks.

Figure 26; reach trucks for double deep pallet racking

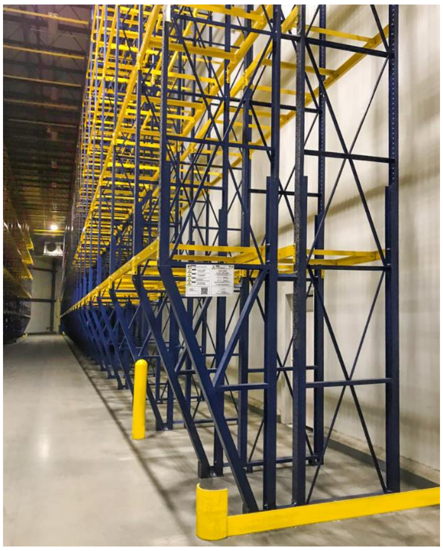

Figure 27; pallet rack with cove for truck

4.2.3 Layout 2: Layout based on small aisles

The layout that can be seen in Figure 28 is based on small aisles and vertically oriented pallet racks. The area with the lines is the area with pallet places. The aisles are all 3.2 meters broad, this means that a forklift truck can still operate in these aisles. This is also because on a pallet there is a maximum load of 600 kg, this applies to the pallets that are standing in the warehouse. This can differ sometimes. The racks are vertical orientated instead of horizontal which is the case right now. The storage of the pallets will be more efficient with this layout. The accessibility is high and there is no double stacking for the pallets. The area that is not filled with lines is meant to be for transport boxes. The option is here to put all the transport boxes into the racks or leave some racks away and put them on the ground because the cantilever racks are not used. For the transport boxes there are two racks and one spot to stall them on the ground if they are too big for the pallet racks. The dimensions of the transport boxes differ a lot, the length is sometimes small and sometimes long. The height of the pallet racks is 4 and 5. This is because the dimensions from the materials on the pallets differ and the height of 5 is possible and creates more pallet places. In the calculations the mean height is considered, which is 4.5.

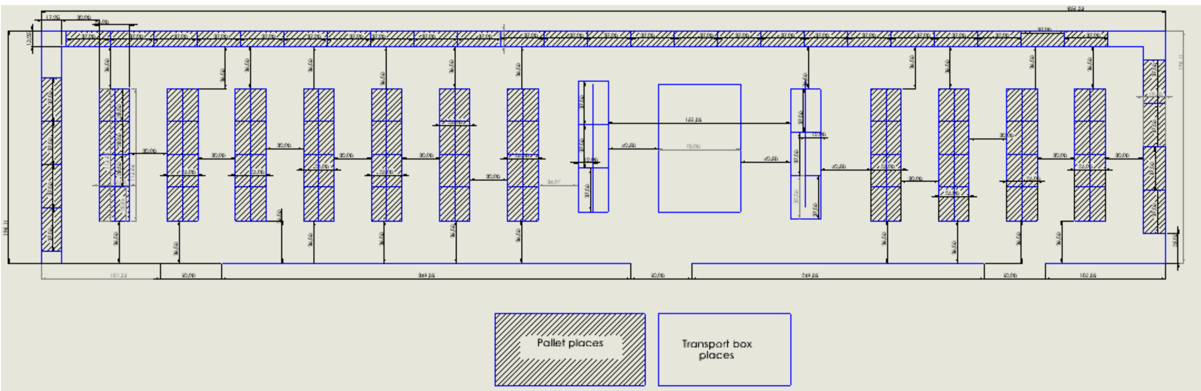

Figure 28: layout based on small aisles

4.2.4 Layout 3: Layout based on mobile racking

Where floor space is very expensive, a warehouse can be made very compact if the units of racking are movable by being mounted on rollers. Only enough space for one access aisle is then required, as the operator can ‘move’ the aisle merely by moving the units (by power, by hand wheel or by pushing) to create a way through to a particular bay. But here, of course, floor space is being saved at the expense of a slowing down in the load-retrieving operation (Richards, 2014).

Mobile rack systems can also be automated, which means that a strong engine is applied to move the racks once an escapement mechanism at the front of the racks, e.g., a button, ripcord, or light barrier, is activated. An open aisle can then be accessed by a human picker to pick the stock keeping unit (SKU).

If the rack systems are automated, the time to wait will be less. Only on the left side is the mobile racking implemented in the layout which can be seen in Figure 29. There are two aisles that are accessible, so that the accessibility will be higher than when there is one aisle. There is a big rectangle on the figure which indicates a place where transport boxes can be stalled. The area is big enough to store transport boxes that are many. Also, the pallet places can be used to store the transport boxes on the right side of Figure 29. In the middle there is a door, so that the distance travelled is not that high. Also, here and there some extra space is added. The height of the pallet places is 4 on the left side, on the right side two racks are 5 high.

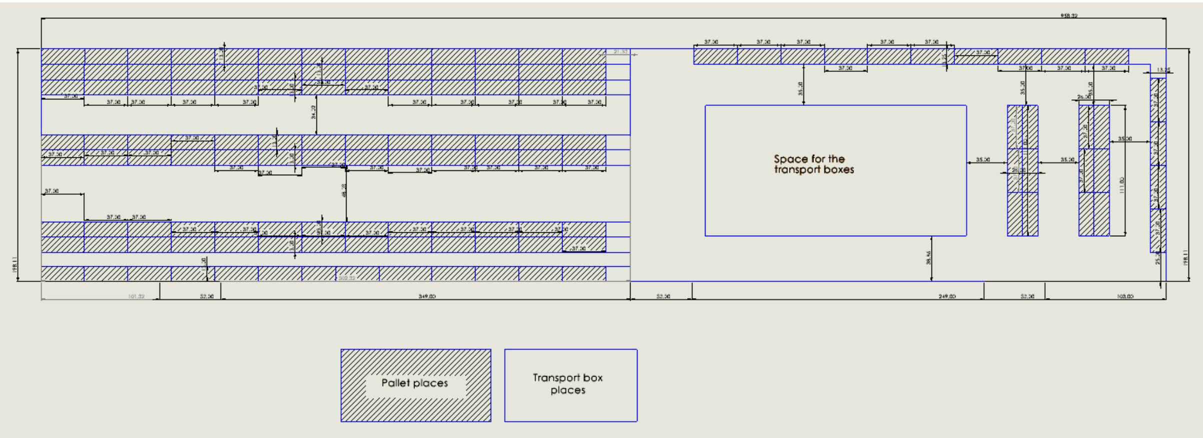

Figure 29: layout based on mobile racking system

4.2.5 Layout 4: Layout with push back racking

The layout with push back racks consist of two vertical side with push back racks, which creates many pallet places. On the horizontal side there is a double rack which creates more pallet places compare to the current situation which is a single rack. There are also two long racks in the middle, which looks like the pallet racks blocks the middle entrance and exit. The idea is that the middle of those racks can be crossed by going under the rack, which means that some pallet places will be lost due to that, but the travel distance will decrease. The lost pallet places will be 32. The push back racks have a high utilization of the warehouse floor. Because for 5 pallet racks, there is only one aisle necessary. This is not the case for the double racks. The transport boxes can be stalled in the racks and the longer transport boxes can be stalled on the horizontal side of the entrance and exit, where no racks are located.

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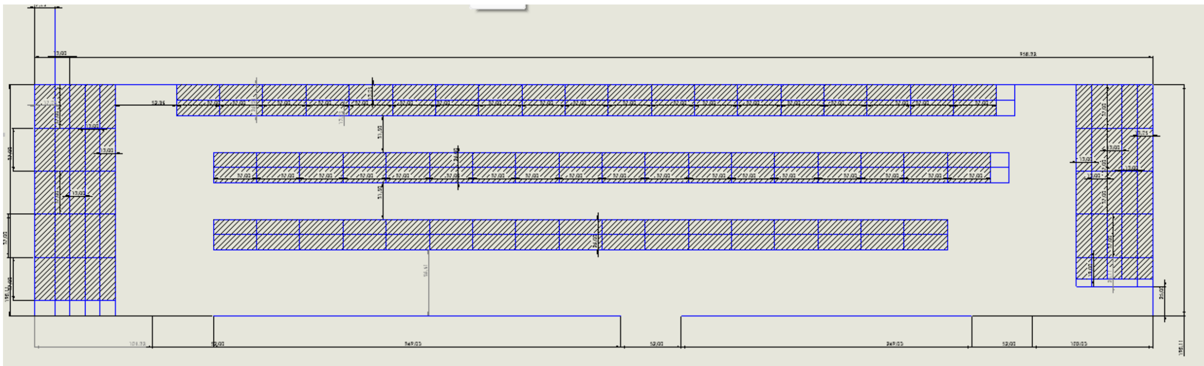

Figure 30; layout with push back racks

4.2.6 Layout 5: Layout with an AS/RS

Automated storage and retrieval systems (AS/RSs) in companies can offer advantages, namely reducing storage costs, minimize labor costs, efficiently using storage space, and better traceability of products. An automated storage/retrieval system (AS/RS) consist of storage rack structures, storage and retrieval machines, conveyors, and pickup/delivery (P/D) stations. A storage/retrieval (S/R) machine is supposed to load and unload products (Fandi, Ghomri, & Kouloughli, 2022).

In Figure 31: layout based on AS/RS system1 the AS/RS system is on the left side of the layout. There are some dimensions created for the S/R machine. The AS/RS offers many pallet places. The right side of the layout shows space for the transport boxes that can be stalled on each on the ground and there is also double pallet racking, that creates more pallet places for pallets and for transport boxes. The pallets are retrieved or put away by the machine and the employees only must drive to the pickup/delivery stations.

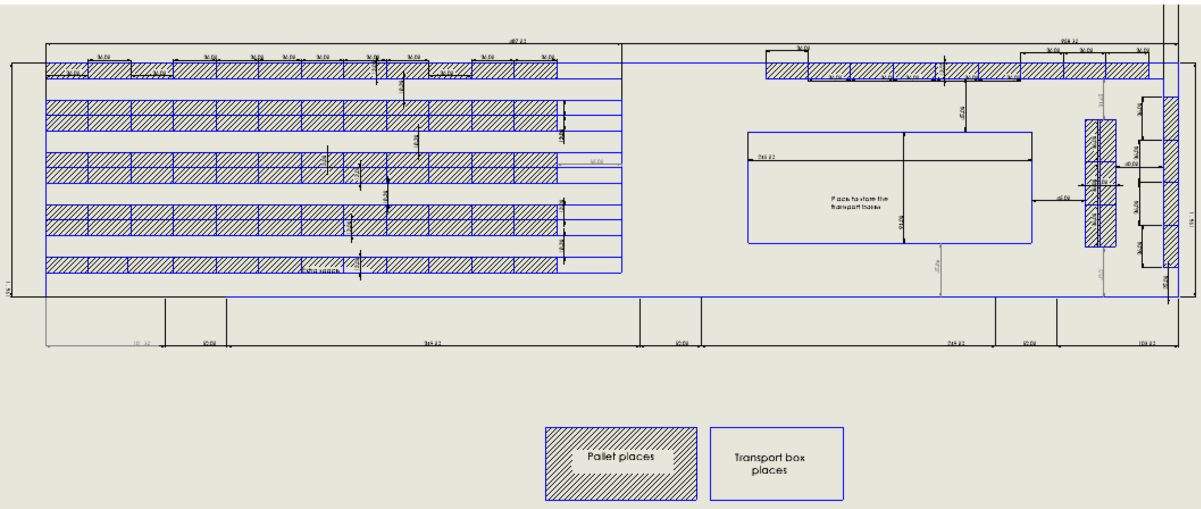

Figure 31: layout based on AS/RS system

The AS/RS system looks promising, but the reality is that the ideal height is 10 meters, the warehouse is only 6 meters high for the AS/RS system (Koster et al., 2007). The AS/RS system is also very expensive, so it won't be very effective and efficient to work this out further. That’s why it will be left out in the rest of the research. The goal is to improve the efficiency, this won’t be the case in this warehouse.

4.2.7 Trucks

Trucks that can operate in the small aisles of the warehouse can be found in Table 6 in the Appendix. These are the ones that can be purchased to operate in the small aisles. The companies are also now using a forklift truck form Still. The table shows the different types of reach trucks with the brand names and the aisle width. The maximal lifting capacity is also indicated, which is important for the company because they operate with pallets with high capacity. The different trucks can be compared and look which one is the most efficient for the companies. For the layout with double deep racks, a special truck must be purchased, to reach to the double racks.

4.3 Comparing the layouts

The KPIs that can be used to compare the different layouts are the accessibility, the pallet places, the travel distance. One of the most important aspects from this research is that the pallet places will be increased, that’s why this is an important KPI. The accessibility indicated how many pallet places are directly accessible for the different layouts. The higher the accessibility, the faster the picking goes. The travel distance will also be calculated for all the different layouts, this will be done by making use of Excel sheets with the distance on it, the occupied pallet places per SKU will be calculated by the total of pallet places per layout and the number of SKUs.

4.3.1 Occupation

In the warehouse there are three different racks that are stored in the warehouse management system (WMS). The right side of the current warehouse has rack number 16 and can be seen in Figure 8. The left side of the warehouse consists of racks 17 and 18, where the most pallet places are located. The pallet places of the different racks can be found in 2.4. One of the KPI’s is the occupation of the warehouse for the three different racks. We did make a data analysis of the month May; the results showed the results, and that the occupation of all racks is below 75%, this means that it is not totally filled. The reality is that many transport boxes are being a hinder for putting away pallets. It looks like the pallet places are all occupied, but in reality, this is not the case. The occupation of the different racks can be found in Table 6; Occupation racks.

Racks	Mean occupation
16	74.7%
17	55.2%
18	70.0%

Table 6; Occupation racks

Error! Reference source not found. shows the occupation of the warehouse in the month May. There are no big fluctuations shown in this month. The occupation seems to be higher to the company, but the problem is that many transport boxes are not conveniently placed. The company would like to increase the capacity with a view to the future. The company expects a steady grow, and this means that the capacity for pallet places and transport boxes must be increased. By also properly placing the materials, the capacity can be better utilized. The occupation looks high when walking in the warehouse, because there is no strategy, and the transport boxes are standing for pallet racks. Also, incoming pallets are stalled on the ground because the employees don't know where to put the pallets.

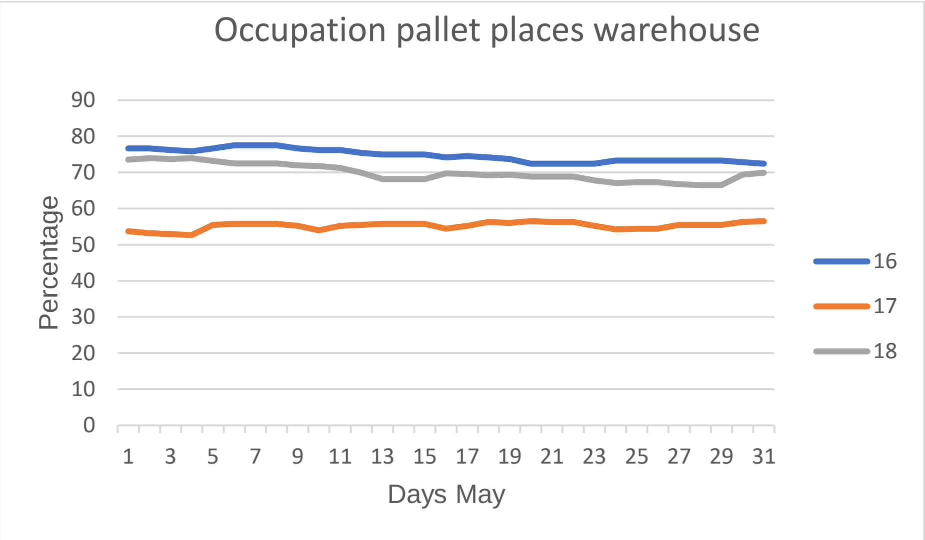

Figure 32: Occupation pallet places

4.3.2 Created pallet places

Table 7 provides the pallet places that will be created with the designed layouts. This will increase for all the layouts. The layout mobile racking has much space for transport boxes. There are no cantilever racks included in the designed layouts because the employees don't make use of them, they are inefficient. It shows that layout based on current situation creates the most pallet places, this is because there is made use of double deep pallet racking, but the aisle width is also decreased. The layout mobile racking also creates many pallet places because there are double racks, and the aisles are small. The layout small aisles also increase the number of pallet places, this is less than the other designed layouts because the layout is oriented differently. The layout based on current situation has the same stacking height what is also now the case. The stacking height of the layout small aisles is for the sides the same as now and for the middle part it is 4.5, because there are racks of 4 high and racks of 5 high. The stacking height of layout with mobile racks is for the mobile racks 4. The side are the same as now and the stacking height of the other racks is also 4.5. The stacking height of the layout with push back racks are for all the racks 4.

Layout	**Pallet places**
Current situation	1393 and cantilever racks for transport boxes
Layout 1: based on current situation	2354
Layout 2: Small aisles	1972 and space for transport boxes
Layout 3: Mobile racking	2120 and space for transport boxes
Layout 4: Push back racks	2516

Table 7; Pallet places

4.3.3 Accessibility

The accessibility means if the pallets are directly accessible, which is the highest in small aisles, because all the pallets are directly accessible which decreases the pickup time. This is lower for the layout mobile racking because the racks must be moved sometimes when picking. The layout based on the current situation has double deep racks which means that the accessibility is also lower. The layout with push back racking has push back racking that is 5 deep. This lowers the accessibility. Currently, theoretically, the accessibility is also 100%, this is lower in reality, because there are many transport boxes stalled before the pallet racks. Table 8; Accessibility provides the accessibility in percentages.

For the accessibility we took a certain date of the system, which showed that many SKUs are double in the warehouse. In total there were 271 SKUs in the warehouse. From these 271 SKUs, 36.5% is equal to 2 or bigger then 2, which means that from these SKUs multiple pallets are standing in the warehouse. This means that when a certain SKU is standing behind the same SKU, the accessibility will still 100% for these SKUs. The percentage of SKUs that is ankle in the system is 63.8%. We decided that when a SKU is standing behind a SKU that is the same, the accessibility still remains 100%. The layout based on the current situation showed that 72.1% is directly accessible, but when 63.8% of the SKUs only represent one pallet in the warehouse, the accessibility is still 100%. All the pallets can be directly accessed. The racks on the layout with small aisles are all directly accessible, so the accessibility is 100%. The accessibility for the layout with mobile racking will be lower because the racks can only be accessed from the open aisles. This means that the accessibility is and will remain 60.8%. The accessibility for the layout with push back racking is 63.6%. 63.8% of the SKUs represents one pallet, we can say this is equal to 63.6%. 18.5% of the SKUs are two pallets of, and the racks that are behind the first racks represent 18.5%, this means that the SKUs where are multiple pallets of can stand behind the same SKU. The also count for SKUs where are three, four and five pallets of. There also remain some SKUs where more than 5 pallets of and these cannot always stand behind each other, this counts for 8.9%. This means that 91.1% of the pallets is directly accessible.

Layout	Accessibility to pallets
Current situation	100%
Layout 1: based on current situation	100%
Layout 2: Small aisles	100%
Layout 3: Mobile racking	60.8%
Layout 4: Push back racks	91.1%

Table 8; Accessibility

4.3.4 Travel distance

In Excel we have made a table that represents the warehouse of Tribelt and De Spiraal. The intention for this is to calculate the distance in an easier way. For all locations the distance has been calculated by calculating the blocks that have been crossed. Every block represents 1 meter in the Excel table. The distance traveled is the number of blocks that have been crossed, this can be horizontal, vertical, and sloping by calculating the distance with the triangle formula (A^2+B^2=C^2). We took the distance in account when picking or retrieving times 2, because the distance traveled is going to a pallet place to store or retrieve a pallet and leaving the pallet spot.

In 4.1.1. is discussed that the material on the pallet must be booked in and out in the system. So, for every pallet place the material must be booked in or out. The distance is therefore based on where the employees have to be to book the material in or out. This can be seen on Figure 11: layout with (in)efficient places, where C16, C17 and C18 indicate the booking spots. The booking spots relates to the racks 16, 17 and 18, what can be found in Table 9. The booking spots in the designed layouts are the same, but the distance traveled is to the closest entrance and exit on the layout. This is now not the case; some pallet places are far from the booking system. The distance travel is based on the model shown in Figure 33; Current layout Excel3. It shows the layout of the warehouse in blocks that has been created in Excel. The travel distance is from the middle of the entrance to a certain pallet place before a certain number of racks. In table 9 the distance is calculated based on figure 33. The same method will be used for the designed layouts.

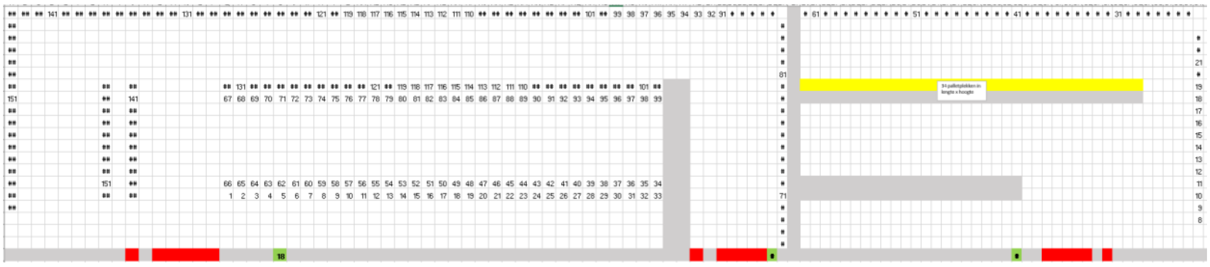

Figure 33; Current layout Excel

The total distance travelled is excluded the transport boxes, because these cannot be found in the system. The transport boxes will therefore be excluded in calculating the travel distance. There is no storage policy for the pallets. The fast and slow movers are just placed somewhere random, which is not optimal for the efficiency of the warehouse. The total distance is now travelled in a month is around 18206.45 meters, which can be found in **Error! Reference source not found.**. This distance will be compared to the designed layouts with a storage policy.

Rack	Distance
16	3148.23 meters
17	9051.32 meters
18	6965.14 meters
Total distance	18206.45 meters

Table 9; Travel distance May

The SKUs that are picked most will have the lowest travel distance in the designed layouts and the least picked will have the longest travel distance, this is based on the number of receipts per SKU. The SKUs are classified into A, B, and C according to the ABC classification. This means that the SKUs that are picked most are classified into A and SKUs that are picked least are classified into C. The distance will be considered from going in and out the entrance and exit. This means going in the warehouse at the entrance to the pallet spot and picking up or dropping of a pallet and going back to the exit.

The mean percentage of occupied pallet places in the warehouse was calculated in 4.3.1. If we want to calculate the average occupied pallet places of the whole warehouse, we can multiply the mean occupation of a rack (16, 17 or 18) divided by 100 times the pallet places from that rack. Summarized, this will give: 74.7%/100*236+ 55.2%/100*393 + 70.0%/100*628= 833 mean occupied pallet places. There were also some pallets that were not standing in the system. So, the real mean occupied pallet places is somewhat higher. This mean that we could say that there are minimal 850 occupied pallet places. For all the layouts that have been made in Solid works are worked out in Excel. The travel distance is calculated with using the blocks of Excel and making using of square root, which has also been done with the distance calculated for the current layout. We divided the SKUs in A, B and C. The occupied pallet place per SKU group will be calculated with the number of orders from that order/ the total amount of orders. This will be the occupied pallet places per group. We calculated for each A, B and C how many pallet places they needed. This is for A around 582.3, for B 214.1 and for C 53.6. This means that for A we can calculate the average travel distance per SKU by looking at the pallet places that have the shortest travel distance. We then take the mean travel distance from the first 582 pallet places that have the shortest travel distance.

Then the mean distance from these occupied pallet places will be considered for a certain SKU group (A, B, or C). The travel distance is calculated with the dimensions that are stated in Excel, in Excel there is made use of square root to calculate the distances. The distance travelled has been calculated for the layout with small aisles, for the layout which is based on the current situation and the layout with mobile racking. The layouts in Excel can be found in Appendix C. There has been made an ABC classification, with A the shortest travel distance and C the longest travel distance. In Table 10; Travel distances SKUs A, B and C, the mean travel distance of A, B and C can be found for the different layouts by calculating the travel distances for all the spots. We take the mean of the 582 shortest calculated distance spots for SKU A. After that, the mean travel distance for SKU B will be calculated and then it will be calculated for SKU C.

	Small aisles	Layout based on current situation	Mobile racking	Push back racks
A	12,69*2 = 25.38	12,56*2 = 25.12	16,24*2 = 32.48	10.23*2 = 20.46
B	16,93*2 = 33.86	16,73*2 = 33.46	25,09*2 = 50.18	14.42*2 = 28.83
C	18,47*2 = 36.94	17,46*2 = 34.92	29,10*2 = 58.20	15.84*2 = 31.68

Table 10; Travel distances SKUs A, B and C

The travel distance that has been calculated in **Error! Reference source not found.**, is based on the SKUs that were picked up or put away during that month. The SKUs are divided in A, B and C, so that the travel distance on the designed layouts can be calculated. The movements from May state that there were 67 movements from SKU A, 91 movements from SKU B and 143 movements from C. Based on these movements, the travel distance can be compared to the current situation, by multiplying the travel distance per SKU group times the movement of that certain SKU. The distances travelled for the designed layouts can be found in Table 11. The travel distance from the layout small aisles is the lowest which can be found in Table 11. This is because the racks are set up very efficiently. The travel distance made in the layout that is based on the current situation is slightly higher than the small aisles. This is since there are double racks, which also will shorten the travel distance compared to the current situation. The table shows that with an ABC classification the travel distance will decrease. This means that picking will be more efficient, and it proves that a classification will improve the travel distance made by the employees.

Layout	**Travel distance**
Current situation	18206.45 meters
Layout 1: Layout based on current situation	67*25.38 + 91*33.86 + 143*36.94 = 10064.14 meters
Layout 2: Small aisles	67*25.12 + 91*33.46 + 143*34.92 = 9721.46 meters
Layout 3: Mobile racking	67*32.48 + 91*50.18 + 143*58.20 = 15065.14 meters
Layout 4: Push back racks	67*20.46 + 91*28.83 + 143*31.68= 8524.59 meters

Table 11; travel distance designed layouts

4.3.5 Score findings

Multiple findings can be compared, namely the accessibility, the number of pallet places and the travel distance for the different layouts. If we score our findings and use weighted scores, we can find the layout that scores the best overall. The scoring is based on the percentage change for the number of pallet places and the trave distance. The formula we used for this is new number – old number divided by the old number. For the accessibility we used the percentage that is already calculated.

Summarizing, let us score our findings using a scale from 1 to 10.

	Accessibility (0.3)	Number of pallet places (0.5)	Travel distance (0.2)	Weighted score
Layout based on current situation	10	6.90	4.47	0.3*10+0.5*6.9 +0.2*4.47= 7.34
Small aisles	10	4.16	4.66	0.3*10+0.5*4.16 +0.2*4.66= 6.01
Mobile racking	6.08	5.22	1.73	0.3*6.08+0.5*5.22 +0.2*1.73= 4.78
Push back racking	9.11	8.06	5.32	0.3*9.11+0.5*8.06 +0.2*5.32= 7.83

We asked management about their relative preference of the three criteria. It is indicated in the table. The scoring is for the accessibility 0.3, for the number of pallet places 0.5 and for the travel distance 0.2. The outcome of the weighted scores shows that the push back racking scores the higher. Also, the layout based on the current situation has a high score. Hence, we recommend the layout with push back racking as number one and the layout based on the current situation as number two.

4.4 Conclusions

There has been made an ABC classification based on the number of receipts. The classification has been made in Table 12: ABC classificationThis classification is used to determine the travel distances of the designed layouts. The distances have been calculated by using the closest travel distance for A, then B and the longest travel distance for C. The occupied pallet places calculated in 4.3.1 gave insight in the mean occupied pallet places, so that we could calculate the distances for these based on the number of receipts. The designed layouts show that for the layout with push back racks the pallet places are most increased, but the accessibility from this layout is lower than now, due to the push back racks and double deep racks. The travel distance also decreased a lot for this layout due to the ABC classification. The travel distance of the layout with push back racking is decreased most, and the pallet places of this layout are increased most, the weighted score of this layout is also the highest. Therefore, we recommend the layout with push back racking and the layout based on the current situation also scores very high. The pallet places for all the layouts are much increased and the pallet places that are created are more than now but compared to the other designed layouts the lowest.

5 Solution analysis

In chapter 5 the results of the different layouts will be analysed. In 5.1 the increased pallet places will be discussed, in 5.2 the improved efficiency will be discussed based on the travel distance and the accessibility and in 5.3 the expected results will be discussed when implementing the chosen solutions.

5.1 Capacity

All solutions will increase capacity, the amount of pallet places will increase for all the designed layouts. The current amount of pallet places is 1393. Assuming that the companies are going for the biggest amount of pallet places and less space for transport boxes, then the pallet places for the layout based on the current situation will increase with 961 pallet places, which is 69,0%. For the layout with small aisles the amount of pallet places will increase with 579, which is 41.6%. For the layout with the mobile racking system, the amount of pallet places will increase with 727, which is 52.2%. For the layout with push back racks, the amount of pallet places will increase with 1123, which is 80.6%. Based on the increased amount of pallet places, the layout with push back racks creates the most pallet places. Also, the layout based on the current situation shows a huge increasement. The fact that these increasements are possible, is because the utilization of the warehouse is higher. There are double deep racks and push back racks on the layouts, which decreases the aisles needed. Smaller aisles also provide more space for storage.

5.2 Improved efficiency

The efficiency will be improved if a storage policy will be implemented. The chosen storage policy is the ABC classification. The fast movers will have the shortest travel distance and the slow movers will have the longest travel distance. This improves the travel distance made by the employees. The current travel distance is long because the storage policy is random right now. By improving the storage policy, the travel distance will decrease as calculated in 4.3.4. The travel distance for the current layout will be 10064.14 meters, which gives a decrease of 44.7%. The travel distance for the layout with small aisles is 9721.46 meters, which gives a decrease of 46.6%. The travel distance for the layout with the mobile racks is 15065.14, which gives a decrease of 17.3%. The travel distance for the layout with push back racking is 8524.59 meters, which gives a decrease of 53.2%. This shows that this is the best improvement on travel distance for the different layouts. Also, the layout based on the current situation and with small aisles shows huge improvements for the distance travelled. If we look at the accessibility, it shows that for the layout based on the current situation, the layout with small aisles and the layout based on the current situation, the accessibility is 100%. The layout based on the current situation shows that the accessibility is 100%, despite the double deep racks, this is due to the SKUs where are multiple pallets of. The accessibility for the layout with push back racks is 91.1%, this is due to the fact that the double deep racks are 5 deep. The layout with mobile racks has the lowest accessibility, which is 60.8%, this makes picking less efficient. If the accessibility is higher, the efficiency will also be higher.

5.3 Implementation

Implementing one of the solutions will cost a lot of money, especially when changing the whole layout. The layout based on the current situation is the cheapest, because the already poured concrete can mostly remain standing. The layout with push back racks, also show many elements of the layout right now. Looking at the pallet places the biggest increasement will be there when the layout is with push back racks. The double deep pallet racks and the push back racks create a lot of pallet places. And the SKUs that are the same can be stored in the not directly accessible racks, this also counts for the slow movers. The layout based on the current situation also increases the pallet places a lot. Because many SKUs have multiple pallets stored in the warehouse, the accessibility for the layout with push back racks still show a high accessibility. The layout with mobile racks and small aisles will cost a lot of money, because these layouts are completely different compared to the current situation. The layout with small aisles will increase the pallet places with the smallest amount, but all the pallet places are directly accessible. The travel distance for the layout with mobile racks is the highest and least efficient because the travel distance is high, and the accessibility is low.

Also, the pallet places must be booked in and out of the system. This increases the travel distance a lot right now, because the employees must pass this system once. The travel distance with the designed layouts is now based on the entrance and exit that is the closest to that place, this decreased the travel distance a lot. The fact that there was of an ABC classification used also decreased the travel distance a lot. The fast movers then have the shorter travel distance then currently. The company could look for another solution for the booking system, so that the distance travelled will decrease.

6. Recommendations and conclusion

Currently there is no storage policy, this means that the travel distance is longer then when there is a storage policy. In this research the ABC classification is applied to the different designed layouts which resulted in a shorter travel distance. It is recommended to use and apply this system immediately this could also be applied in the WMS. The travel distance for the layout with the push back racks has decreased the most. The layouts with small aisles and based on the current situation also show huge improvements. The pallet places for the layout with push back racks create the most pallet places, also the layout based on the current situation increased the pallet places a lot. This is due to the higher utilization of the warehouse floor. The cheapest solution will be when the layout is based on the current situation. The layout with push back racks also shows elements from the current layout, which decreases the costs. The layout with double deep racks has an accessibility of 100% due to the SKUs where are multiple pallets of. The layouts with double deep racks and push back racks has an accessibility of 91.1%, because of many SKUs there are multiple pallets standing in the warehouse. In 4.3.5 the different KPIs are weighted, and the result is that the layout with push back racks have the highest weighted score, therefore we recommend this layout. Also, the layout based on the current situation scores very high, and therefore we also recommend this layout. The other two layouts will not be recommended since the costs will be higher and the weighted score is lower.

It is recommended to put the transport boxes somewhere else because they are a huge hinder. The best recommendation is to have a separate building for the transport boxes, so that they won't hinder the pallet racks. The occupation seems to be under 75%, but it is thought to be much higher. There is no overview due to the transport boxes. It will be effective to put the transport boxes in another area, then there will be more overview, the pallet racks are directly accessible, and more pallet places can be created in the warehouse. The efficiency will also be much higher because extra movements are not required.. The cantilever racks are hardly used, so it is also recommended to put the pallet places in the pallet racks, which is possible. The proposed layouts have more pallet places, which can also be used for the transport boxes. Long transport boxes can be stalled on the warehouse floor and be stacked up each other.

Currently, the pallets must be booked in and out of the system by a certain spot that belongs to that rack. This can be changed by allowing everything to be booked in and out at each location or by choosing the location closest to the pallet location. It is also important that certain parts of concrete are removed so that the pallet locations are more accessible and that the distance travelled will be decreased. The efficiency is due to this lower. Efficiency will become higher when there is made use of a classification and storage policy, and not by putting the pallets anywhere random.

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Appendices

Appendix A

Receipts	Tribelt	De Spiraal
0	3001045, 3001420, 3002867, 3000978, 3001447, 3001431, 3002920, 3000525, 3000523, 3000448, 3000528, 3000167, 3000487, 3001357 ,3001532, 3001359, 3001160, 3000490, 3001031, 3001985, 3001115, 3003365, 3000109, 3001566, 3000484, 3000182, 3000428, 3000402, 3001566, 3000542, 3000163, 3000522	1003050, 1009532, 1004997, 1002361, 1005202, 1003055, 1013721, 1009933, 1005862, 1010933, 1010657, 1016374, 1011271, 1000522, 1009940, 1008801, 1008795, 1007009, 1008734, 1013614, 1008797, 1012458, 1001817, 1011672, 1010601, 1009960, 1010680, 1013717, 1002386, 1000591, 1002482, 1013239, 1011939, 1012175, 1010800, 1008528, 1008792, 1005216, 1004705, 1013720, 1013718, 1001568, 1011073, 1010832, 1018154, 1000334, 1001484, 1004921, 1005131, 1002415, 1002433
1-10 **C**	3000399, 3001735, 3002077, 3000435, 3001633, 3000852, 3000166, 3002291, 3000447, 3000485, 3002284, 3001724, 3002285, 3000291, 3002280, 3003767, 3000474, 3000521, 3000296, 3000436, 3000520, 3000438, 3000408, 3000524, 3000288, 3000394, 3000530, 3000418, 3000443, 3001849, 3000148, 3000442, 3000432, 3002924, 3000541, 3001434, 3000613, 3000452, 3000431, 3000303, 3000426, 3002954, 3000956, 3000467, 3000407, 3000430, 3000469, 3001082, 3000301, 3000450, 3000439, 3000152, 3000425, 3000517	1011074, 1004793, 1004870, 1005311, 1005318, 1002503, 1005321, 1003061, 1005511, 1012311, 1005205, 1005303, 1011943, 1016172, 1004744, 1004988, 1009499, 1011909, 1005324, 1004716, 1005314, 1009538, 1005322, 1005332, 1005309, 1005210, 1003567, 1004890, 1002497, 1003555, 1003558, 1005182, 1003021, 1005211, 1004724, 1011710, 1003140, 1004733, 1002276, 1005196, 1005207, 1005306, 1004691, 1005328, 1004841, 1003136, 1004591, 1004732, 1005204, 1002265, 1005220, 1005066
11-50 **B**	3000395, 3000240, 3000405, 3000472, 3000995, 3001983, 3000617, 3000618, 3001946, 3000503, 3001211, 3000678, 3000391, 3002253, 3000683, 3001745, 3000830, 3000441, 3000535, 3000518	1012582, 1002309, 1005059, 1004560, 1004710, 1002890, 1011711, 1005319, 1005231, 1005060, 1014389, 1004709, 1005351, 1006223, 1003218, 1006221, 1010011, 1002373, 1005326, 1005331, 1005274, 1004998, 1004675, 1005064, 1005308, 1005181, 1002473, 1005269, 1014366, 1005224, 1005393, 1005343, 1005062, 1005359, 1003557, 1005280, 1012073, 1005067, 1013639, 1014387, 1005299, 1005338

51-700 A	3000470, 3000534, 3000532, 3000181, 3000533, 3000468, 3000471, 3000231, 3000538, 3000537	1014388, 1005356, 1004647, 1005229, 1003560, 1004695, 1005399, 1005384, 1005401, 1005284, 1005377, 1005267, 1005400, 1005412, 1005270, 1005282, 1005350, 1012597, 1005230, 1005335, 1004645, 1005272, 1005172, 1005417, 1005273, 1005390, 1005415, 1005357, 1005301

Table 12: ABC classification

Appendix B

Supplier	Name	Number of wheels	Maximum lift height (mm)	Maximum lifting capacity (kg)	Aisle for Europallet 800x1200 (mm)
Crown	RC 5520/25	3	7010	1500	2990
Still	RX 50-10C	3	5620	1000	3010
Jungheinrich	EFG 110k	3	5500	1000	3020
Toyota	7FBEST10	3	6510	1000	3020
Crown	RC 5530/35	3	7010	1500	3045
Still	RX 50-10	3	5620	1000	3064
Jungheinrich	EFG 110	3	6000	1000	3074
Crown	RC 5540/45	3	7010	1800	3110
Crown	SCT 6010 1.3	3	7490	1300	3158
Still	RX 50-13	3	6070	1250	3172
Hyster	A1.3XNT	3	5500	1300	3176
Toyota	7FBEST13	3	6540	1250	3180
Jungheinrich	EFG 113	3	6500	1250	3182
Toyota	8FBE15T	3	7500	1500	3223
Toyota	8FBE15T	3	7500	1500	3223
Still	RX 50-15	3	6070	1500	3226
Hyster	A1.5XNT	3	5500	1500	3230
Jungheinrich	EFG 213	3	7000	1300	3230
Jungheinrich	EFG 215	3	7000	1500	3230

Still	RX 50-16	3	6070	1600	3231
Jungheinrich	EFG 115	3	6500	1500	3236
Hyster	J1.5XNT (SWB)	3	5500	1500	3257
Hyster	J1.6XNT (SWB	3	5500	1600	3257
Crown	SCT 6020 1.3	3	7490	1300	3261
Crown	SCT 6020 1.6	3	7490	1600	3261
Still	RX 20-14C	3	7870	1400	3311
Toyota	8FBEK16T	3	7500	1600	3331
Toyota	8FBEK16T	3	7500	1600	3331
Hyster	J1.8XNT (MWB)	3	5500	1800	3350
Hyster	J2.0XNT (MWB)	3	5500	2000	3350
Hyster	J1.6XNT (MWB)	3	5500	1600	3355
Crown	SCT 6040 1.6	3	7490	1600	3365
Hyster	J2.0UTT	3	6000	2000	3410
Crown	SCT 6040 1.8	3	7490	1800	3413
Hyster	J1.6UTT	3	6000	1600	3415
Hyster	J1.8UTT	3	6000	1800	3415
Toyota	8FBE16T	3	7500	1600	3440
Toyota	8FBE16T	3	7500	1600	3440
Jungheinrich	EFG 216	3	7000	1600	3450
Hyster	J1.8XNT (LWB)	3	5500	1800	3458
Hyster	J2.0XNT (LWB)	3	5500	2000	3458
Hyster	J1.6XNT (LWB)	3	5500	1600	3463

Jungheinrich	EFG 218	3	7000	1800	3469
Jungheinrich	EFG 220	3	7000	2000	3469
Still	RX 20-18P	3	7720	1800	3487
Still	RX 20-16P	3	7870	1600	3487
Still	RX 20-20P	3	7930	2000	3501

Table 13; trucks that can operate in small aisles

Appendix C

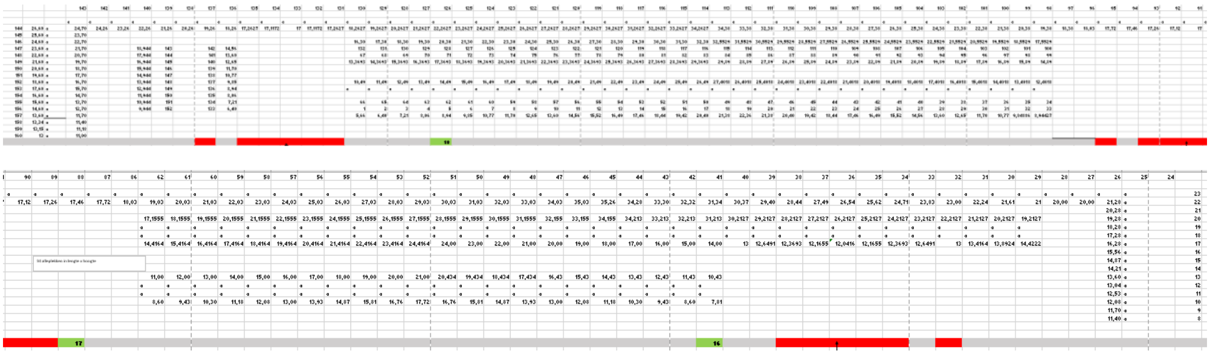

Figure 34; layout based on current situation in Excel

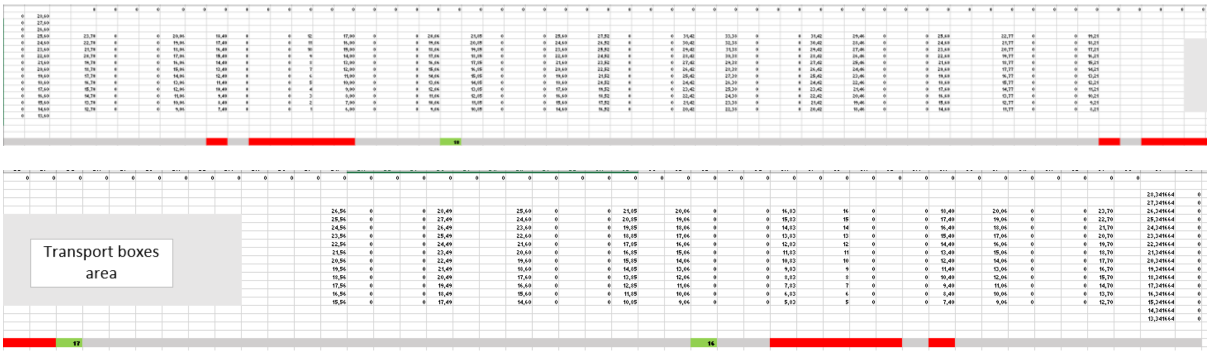

Figure 35; layout small aisles in Excel

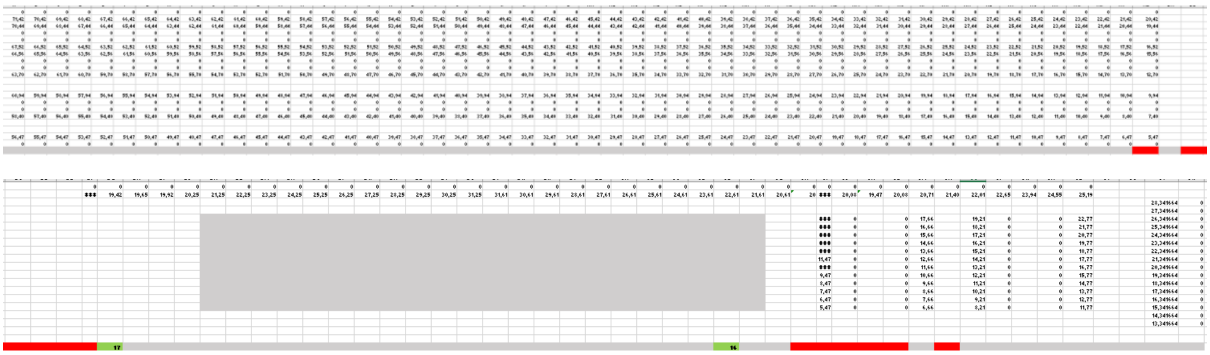

Figure 36; layout with mobile racks in Excel

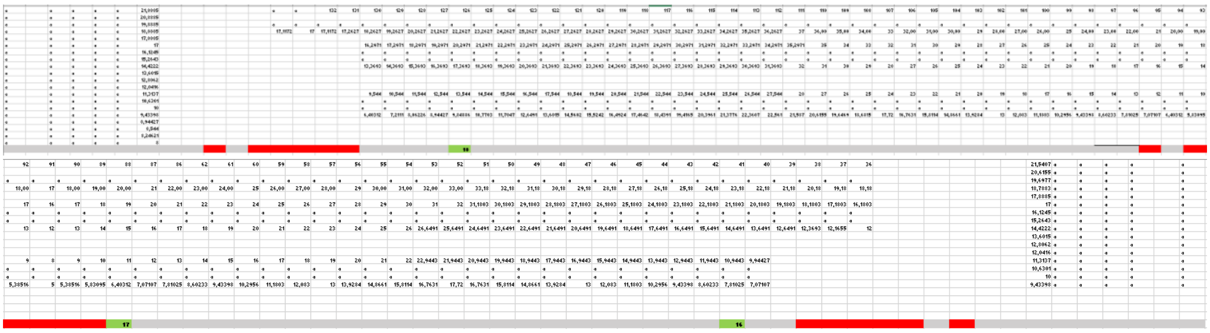

Figure 37: layout with push back racking in Excel