MASTER THESIS

Creating a more efficient flow of goods within the warehouse, through the improvement of storage and order picking

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Document title: Creating a more efficient flow of goods within the warehouse, through the improvement of storage and order picking.

Master thesis for the Master Program Industrial Engineering and Management at the University of Twente.

Status: Final report

Date: *22-02-2019*

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Management summary

Trioliet, located in Oldenzaal in The Netherlands, is a family-owned company in the field of feeding technology. Trioliet is unique as being a complete provider of premium feeding technology for dairy farmers and offering highly comprehensive and specialist range of livestock feeding machines. With about 250 employees and more than 65 years of experience, Trioliet is an important company in the field of feeding technology. Today there are tens of thousands of professional Trioliet users all over the world who enjoy the ease and reliability of their Trioliet machine day after day.

The research problem is described as creating a more efficient flow of goods within the warehouse, through the improvement of storage and order picking. In order to find a solution to this problem, the main research question is formulated as:

> ***How to get the flow of goods more efficient within the warehouse by improving the storage of parts and the picking of orders? Furthermore, what are the savings of these improvements and how can these be implemented?***

The focus of this research lies upon the improvement of the activities between the process of receiving goods and making an order shipment ready. All the processes within the warehouse are in the scope of this research. What happens before arriving or after leaving the logistic center is not within the scope of this research. The main assumption in this research is that all parts just arrive in the warehouse and are reordered when needed.

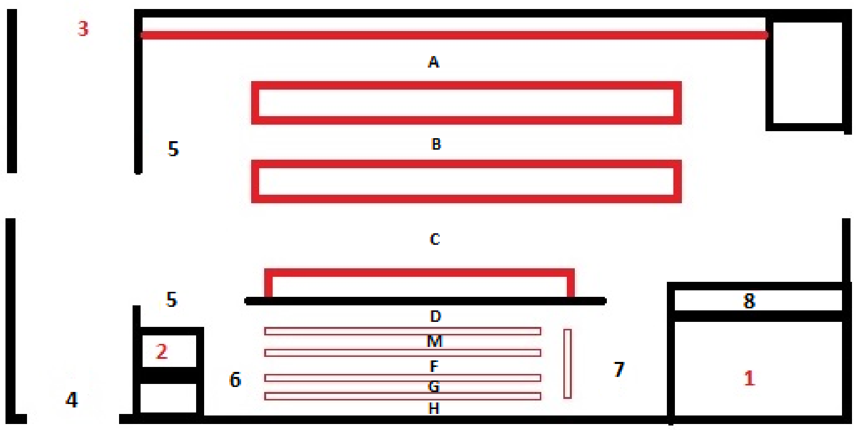
The warehouse of Trioliet is located in the logistic center. The warehouse consists of two I/O points:

<u>I/O point 6, incoming goods</u>

- *Resupply of production*
- *Resupply of suppliers*

<u>I/O point 7, spare parts</u>

- *Spare parts for customers*
- *External warehouses*



1 = Spare parts department
2 = Department incoming goods
3 = Production
4 = Entrance of logistic centre
5 = Temporary storage incoming goods
6 = I/O point incoming goods
7 = I/O point spare parts
8 = Storage for transport

Large parts are located in the pallet area (aisles A, B and C). Smaller parts are located in the shelving area (aisles D, M, F, G and H). Some parts are just located in production, which are parts that are almost not needed for spare parts.

The current layout of the warehouse is not random, but there is also no mathematical or theoretical model used to come to this layout. They have tried to put the parts close to the picking location and group parts that are often in the same order. At the end of the year they check if there are parts located wrongly and translocate them.

Literature mostly addresses the storage and picking of parts. Different storing options are discussed within literature. Random storage means that any location in a warehouse can be chosen, whereas with dedicated storage an SKU is coupled at a specific location. Dedicated storage is based on the idea that fast-moving parts should be located in easily accessible areas. Two dedicated storage methods are discussed in literature:

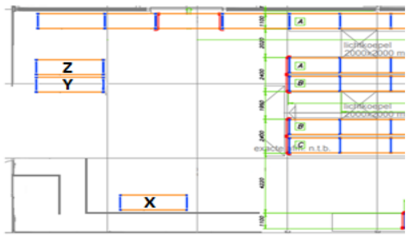
- **COI** Cube-per-Order Index allocate parts to a storage location according to their popularity.
- **OOS** Order Oriented Slotting aims to store parts, that appear together in orders, close to each other.

Five inefficiencies are exposed after observing the current situation, interviewing employees and analyzing data from the ERP system. These five inefficiencies are discussed beneath.

The receiving process

The activities in the receiving area are observed and analyzed. Two inefficiencies are exposed here:

- *Unnecessary search time, because documents are taken from the pallet. The second operator has to pick the documents and search for the box or pallet.*
- *Not enough temporary storage space. Boxes and pallets are located wherever there is space, thereby creating chaos in the receiving area.*



To overcome these problems three new pallet racks are introduced.

- Location **X** Temporary storage for production orders
- Location **Y** Temporary storage for incoming goods
- Location **Z** Extra storage space in the warehouse

With the introduction of these racks the inefficiencies are solved:

- The incoming goods can get a temporary storage location which decreases the searching time.
- On average less space is occupied, because there is more vertical storage space.

No quantified data is computed, but after interviews with those involved and observing the process it can be concluded that the pallet racks will improve the efficiency at incoming goods. It can furthermore be concluded that the new storage racks result in extra storage space, less searching time and a decrease in total ground space used.

Set production

Observations, clocked data and analyzing the created heatmaps show some inefficiencies during the set production:

- *Long travel distances, because the parts within a set are located throughout the entire warehouse.*
- *Set production is done manually, which makes it a time-consuming process*

Travel time

In the old situation the parts are located all over the warehouse and the average travel distance to pick a set is 65 meters. A new storage strategy with as starting point the OOS strategy is designed. With help of this heuristic a new allocation is created. The first 9 shelves of the G aisles are emptied and the parts are relocated. After this reallocation of the set parts the average travel distance to pick a set is 28 meters. This means that a reduction of 56.9% is achieved.

Manual set production

In the old situation the packing of sets and writing of product number is done manually. This requires a significant amount of time. Different options are discussed and a test case is executed.

The test case is done for the '*Trioform knife set*'. Four options are calculated as shown in the table on the right. The best option is to buy pre-packed boxes of this set. A test batch of this pre-packed set is purchased and Trioliet is currently testing it.

How	**Per set**
Employee Trioliet	€ 0.11
Employee Larcom	€ 0.06
Outsource to Larcom	€ 0.09
Pre-packed purchase	€ 0.05

Other options that are discussed are the purchase of a label printer and/or packing machine.

<u>*Label printer*</u>: A label printer replaces the handwritten product numbers. This makes the packaging process a less time-consuming process and provides the sets with a more professional look.

<u>*Packing machine*</u>: A packing machine automates the whole packaging process and can also automate the stickering process. This machine makes the packaging process more efficient.

Storage of parts

Observations, clocked data and analysis of the created heatmaps show two inefficiencies during the picking process:

- *Parts are located throughout the entire warehouse, with long travel distances as a consequence.*
- *Parts are located at high locations with long picking times as a consequence.*

A new storage strategy is created to reallocate the parts. Trioliet makes use of two I/O points, so a combination of class-based and cube-per-order index (COI) is used.

<u>*Class-based*</u>: First the warehouse is divided into three different zones.

- 100-75% of the picks are done at spare parts	I/O point 7	Right
- 100-75% of the picks are done at incoming goods	I/O point 6	Left
- Less than 75% of the pick are done at one location.		Middle

<u>*COI*</u>: In each zone parts are located with the COI approach.
The cube-per-order index allocates the parts to a storage location according to their popularity. Parts that are picked often are located close to the floor and close to the I/O point.

This is done for the pallet area and the shelving area:

<u>*Pallet area:*</u> With this new storage strategy the travel distance from both I/O points decreases and the usage of a reach truck is minimized.

- For I/O point 7 the travel distance reduces from 40.8 meter to 29.4 meter, which means that a reduction of 27.9% is achieved.
- For I/O point 6 the travel distance reduces from 45.7 meter to 26.7 meter, which means that a reduction of 41.6% is achieved.

<u>*Shelving area:*</u> With this new storage strategy the travel distance from both I/O points decreases and the usage of a ladder is minimized.

- For I/O point 7 the travel distance reduces from 18.4 meter to 15.3 meter, which means that a reduction of 16.8% is achieved.
- For I/O point 6 the travel distance reduces from 17.6 meter to 11.8 meter, which means that a reduction of 32.9% is achieved.

Order picking

The activities of the order picking process are observed and analyzed. Five inefficiencies are found:

- *Parts are picked in small amounts, because parts are heavy and difficult to handle.*
- *Long travel times, because part picking with a reach truck can take up a lot of time.*
- *Long travel times, the operator has to travel through the whole warehouse.*
- *Ladders that are used in the shelving area stand in the way during the picking process.*
- *Equipment used makes the picking process a more time-consuming one.*

These inefficiencies are discussed on the basis of three different sections. First picking zones are discussed, followed by ladders in the shelving area and the last part is about the equipment used in pallet area.

Picking zones

A solution for the long travel times is the introduction of zone picking. Firstly, a picking policy with two zones is advised which can be extended later on. These zones are:

- The shelving area and first three layers of pallet area, where these parts are picked by hand.
- The other layers of the pallet area, where these parts are picked by a reach truck.

Currently there is only one reach truck present in the warehouse that is used at both I/O points. This has as a long travel time, searching time and start up time as consequences. Besides that, the reach truck is occupied frequently and thereby the waiting time increases.

With these advised picking zones the same employee can stay on the reach truck and pick parts needed for both I/O points. This reduces the total picking time significantly.

At a later stage this zoning can be extended to three zones. Then Trioliet can divide the shelving area and the first three layers of the pallet area in two different zones.

Ladders in shelving area
A solution for the ladders is already implemented in the new allocation strategy namely to not use the highest layer for bins, but only for overstock. This minimizes the usage of the ladders, such that the ladders can be located outside the shelving area and only gathered when needed.

When this solution is not working, another solution is proposed. This solution encompasses the introduction of a track ladder. This ladder is attached to a rod in the shelving area. When the ladder is folded the cart can pass the ladder.

Equipment used in pallet area
At Trioliet they are using a cart to pick parts in the pallet area. The operator has to walk through the warehouse what can take an enormous amount of time. Beside that large parts are difficult to transport with the cart, what can result in part picking instead of order picking.

The order picking process can become more efficient by introducing a ride-on picking truck. The operator can stand on the truck, what decreases the travel time. Beside that the picking truck can transport pallets or other storage material, what increases the storage space and storage options.

Investigate other options: Automation

In this research the benefits of automatization in the shelving area are explored. This research was motivated by four inefficiencies in the shelving area.

- A lot of ground space is needed to locate all the parts.
- There is a lot of travel time between the different parts.
- Parts are located on high layers, so a ladder is needed.
- Parts are located on a low and therefore not ergonomic working height.

A solution for these problems may be the introduction of a goods-to-person storage system. With the help of external companies it is concluded that two options are interesting for Trioliet: the VLM and the vertical carousel.

Vertical carousel: A vertical carousel is built with carriers attached in fixed locations to a chain drive. Movement is powered by a motor, which sends the carriers in a vertical loop around a track.

Vertical lift module: A VLM consists out of two columns of trays with a mechanical extractor positioned in the center. This extractor travels between the stored trays, automatically locating and retrieving them when needed.

With the introduction of this new storage system the inefficiencies are solved.

- 86% less ground space is needed, because of a high utilization level and the usage of vertical storage space.
- Ergonomic working height. The tray can be delivered at an individually set working height.
- Travel time reduction, because of the goods-to-person principle.
  180-200 picks per hour with a goods-to-person storage system against 70-80 picks momentarily.

Despite that a lay-out for the implementation is provided, further research is needed before implementing a goods-to-person system. When implementing the correct system the picking process improves significantly and the investments ought to be repaid.

Conclusion

Based upon this research it can be concluded that the efficiency for the warehouse of Trioliet can be improved by implementing the provided recommendations. An implementation plan is created to implement the recommendations and to maintain the efficiency. Beside that a roadmap for the different inefficiencies is created.

Preface

Dear reader,

This report is the result of my graduation project for the *Production & Logistics Management* specialization of the *Industrial Engineering and Management* Master's degree at University of Twente. Writing this thesis has been an exciting experience and I would like to thank everyone who contributed to the success of this project. In this preface I would like to thank several persons in particular who have helped me with the realization of this thesis at Trioliet.

First of all, I would like to thank all the employees of Trioliet for their contribution to this research. Their enthusiastic and open attitude contributed greatly to this research. I have experienced Trioliet as a social, open-minded and helpful company. In particular, I would like to thank the employees of the logistic center for their effort during the guidance of my Master Thesis.

Secondly, I would like to express my gratitude to my supervisor Dr. Peter Schuur who kept giving me critical help and feedback when needed. Furthermore, I would like to thank my second supervisor Ir. Henk Kroon for the guidance and feedback.

Last but not least I would like to thank my family and friends for their support and help. Especially everyone who proofread my thesis.

I wish you a lot of pleasure in reading my Master Thesis,

Kind regards,

Stijn Hulshof

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List of abbreviations

AIMMS	=	Advanced Interactive Multidimensional Modeling System
AS/RS	=	Automatic Storage and Retrieval System
COI	=	Cube per Order Index
EOQ	=	Economic Order Quantity
ERP	=	Enterprise Resource Planning
FIFO	=	First In First Out
ILP	=	Integer Linear programming
I/O	=	Input / Output
JIT	=	Just-In-Time
LIFO	=	Last In First Out
OOS	=	Order Oriented Slotting
QAP	=	Quadratic Assignment Problem
SKU	=	Stock Keeping Unit
VLM	=	Vertical Lift Module

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Chapter 1 - Introduction

In order to obtain the Master title Industrial Engineering & Management at the University of Twente I have performed research about the efficiency of the flow of goods within the logistic centre at Trioliet.

The ever-increasing trend towards more product variety and short response times has placed a tremendous emphasis on the ability to establish smooth and efficient logistic operations (Rouwenhorst, et al., 2000). A large proportion of the companies offer a next-day delivery to customers from inventory (Baker, 2015). The efficiency and effectiveness in a distribution network is largely determined by operating the warehouse. In a warehouse, products can be stored and supplied when the customer needs the product. Market competition requires continuous improvement in the design and operation of production-distribution network, which in turn requires higher performance from warehouses (Gu, McGinnis, Goetschalckx, 2006).

The logistic centre of Trioliet is built in the year 2015. A part of this logistic centre is the new warehouse. With the introduction of this new warehouse they created more space for parts and the efficiency is thereby improved. However, Trioliet still thinks that there is room for improvement upon its efficiency.

The goal of this research is to analyze the main activities in the warehouse and come up with improvements regarding the efficiency of these activities. The current performance is analyzed for exposing inefficiencies. Literature is reviewed and practical solutions are thought of for solving these inefficiencies. New solutions are judged upon the improvement of the efficiency of the warehouse. This research ends with a final conclusion and accompanying recommendations.

The upcoming chapter provides an overview of Trioliet, its business processes and their products. The third chapter describes the research structure with accompanying research motivation, research objective, scope, research questions and the research plan. The fourth chapter describes the current situation at Trioliet with the layout of the warehouse and the different processes that occur within this warehouse. Relevant literature regarding storage and picking methods in a warehouse is described in Chapter 5. In Chapter 6 the different inefficiencies within the warehouse of Trioliet are described. Alternative solutions for these inefficiencies are given in Chapter 7 and these solutions are tested in Chapter 8. An implementation plan for the chosen alternatives is described in Chapter 9. Finally Chapter 10 contains the conclusions and recommendations that can be withdrawn from this research. Used literature in this research is added in a reference list.

Chapter 2 - Trioliet

This chapter provides background information of Trioliet. Section 2.1 describes general information about the company. Section 2.2 discusses the variety of products at Trioliet. In Section 2.3 the logistic centre of Trioliet is explained.

2.1 Trioliet

Trioliet is a family-owned company, founded in 1950 in the city of Purmerend. The brothers Max, Fred and Cees (trio) Liet founded the company and named it Trioliet. In 1958 Trioliet took over Mullos and the decision had been made to move to Losser. Since 1997 the headquarter of Trioliet is located in Oldenzaal which is depicted in Figure 2-1. With approximately 250 employees and more than 65 years of experience, Trioliet is an important and valued company in the field of feeding technology. Trioliet is unique by being a complete provider of premium feedings technology for dairy farms. Thereby, they offer a highly comprehensive and specialist range of livestock feeding machines. All the machines are geared towards helping modern dairy farmers manage a farm as efficient as possible. 'Innovation and customization are major spearheads of our business and it is not without good reason, today, over 80% of our mixers are exported to more than 50 countries worldwide' (Trioliet, 2018). Today there are tens of thousands of professional Trioliet users all over the world who enjoy the ease and reliability of their Trioliet machine on a daily basis.

FIGURE 2-1, TRIOLIET OLDENZAAL (TRIOLIET, 2018)

2.2 Products

Trioliet offers a significant range of livestock feeding machines that are applicable for certain purposes. Thereby, the specialization of these machines is of high quality. Examples of such machines are silage cutters, diet feeders, self-loading or self-propelled mixer feeders and complete automatic feeding systems. Three examples of typical products of Trioliet are the Solomix, Triotrac and the Turbofeeder which are evaluated in the following sections:

Turbofeeder silage cutter is a silage cutter with top unloader. The top unloader, which can also be mounted on an existing Turbobuster silage cutter, makes discharging cut silage blocks. A simple, comfortable and time-saving task. Thanks to the adjustable discharge speed, the top unloader is suitable for all types of unprocessed feed. Including both short-cut and long material.

FIGURE 2-2, TURBOFEEDER (TRIOLIET, 2018)

FIGURE 2-3, SOLOMIX (TRIOLIET, 2018)

The Solomix 3 ZK is a mixer feeder wagon with three vertical mixing augers and two discharge slides. These trailed mixers have been developed for cattle farmers who want to process large quantities of cattle feed in a very short time.

The Triotrac is a self-propelled mixer feeder with two hydraulically driven vertical augers. The cutting-loading system of this machine leaves an optimal vertical cutting surface on the silage. The comfortable and spacious cabin features a hydraulic vertical adjustment system and guarantees that the user has the best possible view.

FIGURE 2-4, TRIOTRAC (TRIOLIET, 2018)

2.3 Logistic centre.

In 2015 Trioliet opened an additional assembly hall and a new logistic centre, with a total area of 7,400 m^2. This new logistic centre and assembly hall expanded the company premises to more than 51,000 m^2. In this new logistic centre the warehouse of Trioliet is located. Almost all the inventory of Trioliet is stored in this warehouse and thereby most of the part flow happens through this specific warehouse. Besides this warehouse in Oldenzaal, Trioliet has supporting warehouses in the United States and in China.

The main focus of this research relies upon the product flow happening within the warehouse in Oldenzaal. All the incoming goods are received in this logistic centre. The main activities that are performed in the logistic centre are: receiving, storing, order picking and shipping. Usually, the parts that arrive at the logistic centre are stored for a short or long period of time. However, some of the parts are sent directly to other departments of Trioliet for further processing.

There are three departments located in this logistic centre: spare parts, service and incoming goods. For this research, in-depth research is performed for the spare parts department and the incoming goods department in particular.

The spare parts department is responsible for the handling of all the spare parts. Thereby, the department is primarily responsible for the supply of spare parts at the external warehouses and the worldwide dealer network of Trioliet.

The incoming goods department is responsible for the internal handling. All the incoming goods are passing this department, where the department is responsible for the storage of the parts and the supply of production.

FIGURE 2-5, WAREHOUSE TRIOLIET (TRIOLIET, 2018)

Chapter 3 - Research structure

In this chapter the structure that is used throughout this research is discussed. In Section 3.1 the motivation for doing the research is explained. In Section 3.2 the main objective of this research is explained. The research questions and the research plan are introduced in Section 3.3. The scope and limitations are discussed in Section 3.4. In Section 3.5 the eventual deliverables of this research are discussed. This chapter ends with a small summary in Section 3.6.

3.1 Research motivation

For Trioliet it is extremely important that the machines are working correctly in order to ensure that all the cattle can be fed on time. When there is a defect with a certain machine, the spare parts department is responsible to send the parts for maintenance. Logically, it is important for Trioliet that the spare parts arrive as fast as possible at their destination in order to continue working.

The warehouse of Trioliet is responsible for the supply of parts, both on an external and internal basis. With regards to the external warehouse, the warehouses in China and the United States are supplied. Furthermore, external customers are supplied form the Trioliet warehouse. The matter of internal supply concerns the refill of the warehouse itself and moreover the resupply of production.

Due the enormous growth of the company there has been a lot of pressure on the spare parts department. Furthermore, the warehouse was completely occupied. Because of this, Trioliet build a new warehouse in 2015. With the introduction of this new warehouse they created more space for spare parts and the efficiency of the picking process is improved. However, Trioliet still thinks that there is potential for improvement. To be able to achieve these improvements, Trioliet created 'vision 2020'.

'Vision 2020' started in the spring of 2018 with as goal to improve the efficiency in the logistic center. Three employees of Trioliet are in addition to their own tasks active with efficiency improvement within the warehouse. They are focusing on the whole warehouse and try to improve the overall efficiency. To support 'vision 2020' and create a more academic approach this research is started.

3.2 Research objective

The objective of this research is to create a more efficient flow of goods within the warehouse. This research will focus on the improvement of efficiency of the activities that take place within the warehouse. Main activities in the warehouse are receiving, storing, order picking and shipping.

This main objective can be divided into two parts. Namely: the storage of the parts and the picking of the orders.

- The storage of the parts concerns storing all the incoming parts that are needed within the warehouse. Currently, there is a storage policy. This storage policy is analyzed and together with the other policies tested upon efficiency.
- The picking of orders encompasses picking all the parts of a particular order. The objective of this part of the research is finding the most efficient ordering picking process. To do so, different options are reviewed.

With the information of these two steps the main objective of the research can be answered. We define the research objective of this research as:

Creating a more efficient flow of goods within the warehouse, through the improvement of storage and order picking.

To fulfill this research objective, several questions have to be answered throughout this research. One main question and multiple research questions are created. These research questions should collectively form an answer to the main question. These questions are discussed in Section 3.3.

3.3 Research question and research plan

The described problem leads to the following main research question:

How to get the flow of goods more efficient within the warehouse by improving the storage of parts and the picking of orders? Furthermore, what are the savings of these improvements and how can these be implemented?

Multiple research questions are used to structure this research. These research questions are presented and described in the following part.

Chapter 4 - Context analysis

1. *What is the current situation at Trioliet regarding the storage of parts and picking of orders?*

Chapter 4 has the objective to obtain detailed insights in the current situation at Trioliet. In this chapter the current way of storing the parts and picking the orders is analyzed. Furthermore, the factors that influence the storage and picking of the orders are analyzed. The research question is answered through interviews and by being part of the processes.

Chapter 5 – Literature study

2. *Which methods for the storage of parts and picking of orders are available in literature?*

After gaining insights in the current situation, the literature study of this research is performed. Literature emphasizing storage and picking within a warehouse are gathered and reviewed. The methods and techniques found in the literature can help in answering the main research question.

Chapter 6 – Current performance and bottlenecks

3. *What are the root causes for the long order picking times?*

After mapping the current situation and analyzing the literature the root causes of the long order picking times are analyzed. It is important that all the possible causes for this long order picking times are analyzed and that everyone involved in the process is included within the analysis.

Chapter 7 – Solution design

4. *What is a suitable picking policy and how should the parts be stored to create an efficient flow of goods?*

In this chapter a suitable picking policy is developed together with a storing plan. In here, the different factors that influence the picking policy are considered. The layout of the warehouse is also analyzed, to investigate if there are other storage options.

Chapter 8 – Solution test

5. *What is the effect of the new order picking process and the new storage of parts?*

After the solution design is created in Chapter 7, the new solutions are tested within this chapter. In this chapter the old situation is compared with the new solution design.

Chapter 9 – Implementation and maintenance

6. *How can Trioliet improve their processes based on the results found?*

Within this chapter an advice for Trioliet regarding improvements is provided. Based on the results from Chapter 7 and 8 an eventual implementation plan is created.

Chapter 10 - Conclusions and recommendations

Finally the main research question is answered based on the results of the earlier findings upon the different questions. Conclusions are drawn from the results and recommendations for Trioliet are provided.

3.4 Scope and limitations

The focus of this research lies upon the improvement of efficiency of activities between the process of receiving goods and making an order shipment ready. The main activities during this process are receiving, storing, order picking and shipping (Rouwenhorst, et al., 2000).

The physical layout of the warehouse is recently implemented and hardware cannot be changed. The procurement of products, stock management and supplier agreements are not included in this research. The focus of this research does not go beyond the warehouse, what happens with a part after leaving the warehouse is not part of the scope of this research.

As mentioned all the processes within the warehouse are part of the scope. How and in what amount the parts arrive in the logistic center is not within the scope. The purchase of parts and possible out of stock is also not within the scope of this research. The assumption in this research is that all parts just arrive in the logistic center and are ordered when needed.

Potential improvement of the current ERP system are excluded of this research. The ERP system is out dated and Trioliet is currently implementing a new ERP system. With the implementation of this new ERP system a lot of improvement can be achieved. Therefor changes regarding the current ERP system are excluded from this research.

3.5 Deliverables

The deliverables of this research contain a report, an implementation plan and a maintenance plan. The implementation plan is a plan on how to implement the advices for possible improvements from this report. The maintenance plan is an advice how to keep the efficiency at a high level within Trioliet in the future.

The last deliverable is this report. This report contains an introduction of the company (Chapter 2) and the problem is introduced (Chapter 3). Thereafter the current situation of Trioliet regarding the storage and picking of parts is discussed (Chapter 4). After these introducing chapters a literature review regarding the storage of parts and picking of orders is gathered in Chapter 5. In Chapter 6 the root causes for the inefficiency in the storage and picking of parts is discussed. After analyzing the current situation and the root causes, possible solution are presented and analyzed (Chapter 7). In Chapter 8 the solution are tested and after this testing an implementation plan is created (Chapter 9). Conclusions and recommendations for further research are presented in the last chapter of this report (Chapter 10). Finally a list of literature is added for the references used in this report.

3.6 Summary

In this chapter the research structure is described. The motivation for doing the research, the eventual objective and corresponding scope of the research are described. The design of the research is divided into several sub questions that are answered throughout this report. The sub questions that are established and answered eventually are:

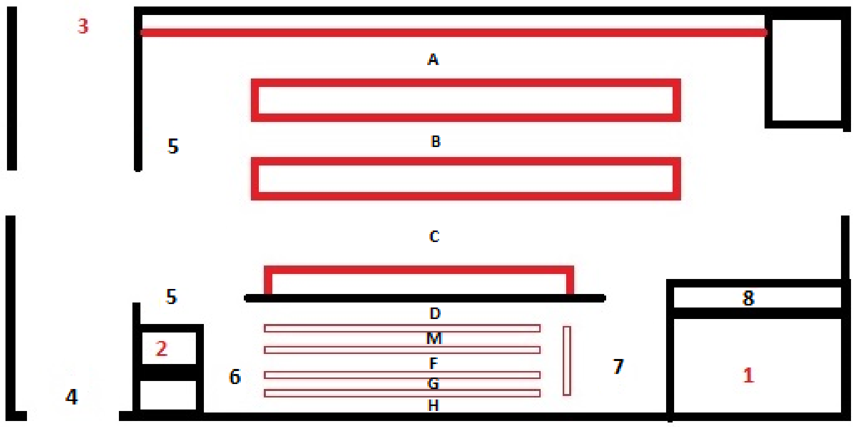
1. What is the current situation at Trioliet regarding the storage of parts and picking of orders?
2. Which methods for storage of parts and picking of orders are available in literature?
3. What are the root causes for the long order picking times?
4. What is a suitable picking policy and how should the parts be stored to create an efficient flow of goods?
5. What is the effect of the new order picking process and the new storage of parts?
6. How can Trioliet improve their process based on the results found?

Chapter 4 - Context analysis

This chapter describes the current situation at Trioliet. Within this chapter the first sub question is discussed: "What is the current situation at Trioliet regarding the storage of parts and picking of order?". In Section 4.1 the layout of the logistic center is explained. The receiving process is discussed in Section 4.2. Section 4.3 consists the storage locations and the storage policy used at Trioliet. In Section 4.4 the picking policies for the different orders are discussed. In Section 4.5 the color coding of the different parts within Trioliet is explained.

4.1 Layout

An overview of the layout of the distribution centre is shown in Figure 4-1, with accompanying explanation of the different areas.



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6 = I/O point incoming goods
7 = I/O point spare parts
8 = Storage for transport

FIGURE 4-1, MAP LOGISTIC CENTER TRIOLIET

The logistic center consists out of different parts. The entrance of the logistic centre is at point 4. All the couriers with incoming goods arrive here. All the parts that are delivered are firstly placed at point 5. There are two I/O points in the warehouse represented by numbers 6 and 7. Location 6 is responsible for incoming goods and picking the parts for production and suppliers. Location 7 is responsible for the order picking of spare parts and the external warehouses. When an order is ready for shipment it is located at position 8 until a shipping company comes by to pick the order. There are two offices that are of importance within this research, located at numbers 1 and 2 respectively. At the office of location 2, all the received goods and internal flow of goods are handled. The office located at number 1 is the spare parts department. This department is primarily responsible for all external affairs. The production hall is located in the left upper corner of the logistic centre and starts at point 3. The warehouse consists of pallet racks and shelves which are represented in red. The pallet racks contain of three aisles: Aisle A, Aisle B and Aisle C respectively. The shelving area consists out of five aisles: Aisle D, Aisle M, Aisle F, Aisle G and Aisle H.

Trioliet uses diverse material handling equipment for picking, storing and pallet movements. A fork truck or an electric pallet truck is used to move the parts in and out of the warehouse. Furthermore, this fork truck is used for the picks that are performed in Aisle C. A reach truck (Figure 2-5) is used to move pallets within the warehouse and pick parts in the pallet rack area also known as Aisle A, Aisle B and Aisle C. For the lower level parts and the parts in the shelving rack area, a cart is used (Figure 6-17). These carts are used throughout the entire warehouse and in all the different aisles. When small parts are picked from production, a bike is used.

On average 17 employees work at the logistic centre. Six employees work at the spare parts department (Location 1). Two employees work at the incoming goods department (Location 2). Five employees work at the incoming goods I/O point (Location 6) and four people work at the spare parts I/O point (Location 7).

4.2 Receiving process

The first main process in a warehouse is the receiving of goods. The receiving of goods at Trioliet is done at the entrance of the logistic centre. An employee from the incoming goods department opens the gate and the truck can drive into the logistic centre. Parts can arrive both from a supplier or from the production department. The process from arriving until the parts are located is visualized in Figure 4-2 and is further explained.

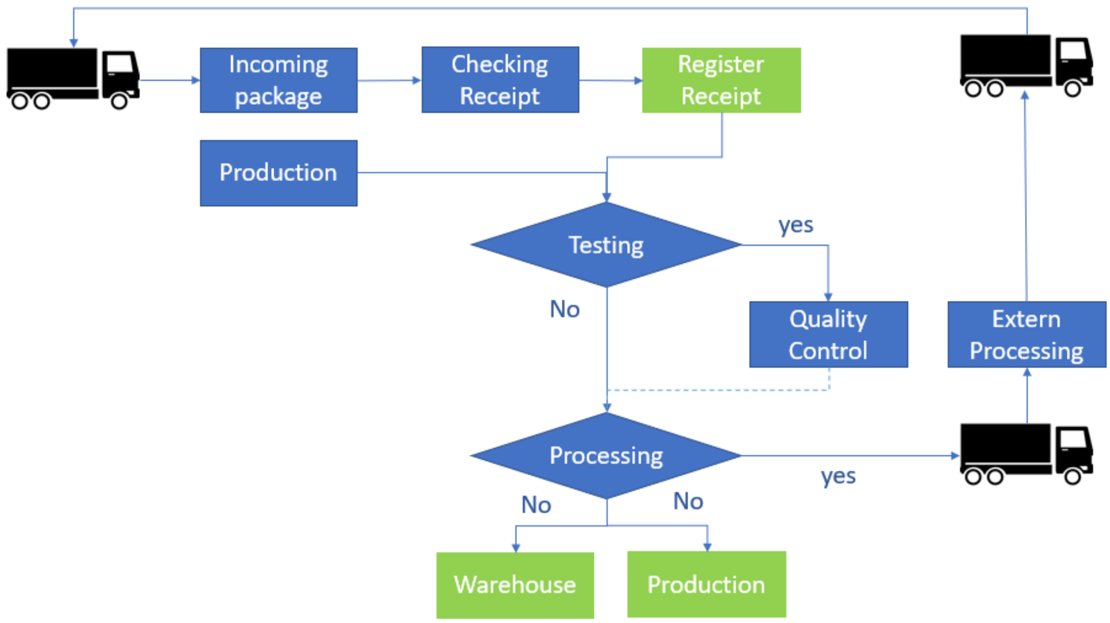

FIGURE 4-2, FLOWCHART INCOMING GOODS

External:
A truck can be unloaded after the supplier has docked the truck at a specific loading dock. The truck is unloaded by an employee of the incoming goods department and the goods are placed into the receiving area. The goods are first checked regarding the consignment note of the supplier. An internal document is filled out and the information is checked based upon the amount of delivered parts. After the incoming goods are checked, an employee can start unpacking the boxes. Some parts need testing and then these parts can be sent to the quality control department for further testing. The other parts are moved directly to their location in the warehouse or send to production. During the unpacking process a check is performed to verify if the amount of parts is correct. After the parts are moved to the right location, the internal document is sent to the office and the parts are added to stock.

When parts are sent to production they are located at a temporary storage location until someone brings the parts to production.

Internal:
Regarding the department, the emphasis lies upon the parts that come from production or from quality control. These parts are moved from production or quality control to the receiving area, thereafter they follow the same process. A part receives an internal document and is moved to their location. After moving the parts, the internal document is sent to the office and the parts are added to stock.

4.3 Storage of parts

In this section, firstly the different storage locations are explained. Besides that, the storage policy that is currently in use is discussed.

4.3.1 Storage locations

There are three different storage options: pallet racks, shelves and products from production. These three different options are further explained below.

Pallet racks: In this area the parts are stored in standard aisle pallet racks represented in Figure 4-3. In total there are three aisles in the warehouse named A, B and C. These three aisles have different sizes and a different amount of pallet racks. The total number of pallet places is 2213. These pallet racks are partly used for spare parts, but also for parts that are waiting until they are needed for production. Most of the stock within the pallet racks is used partly for spare parts and partly in production.

FIGURE 4-3, PALLET AREA

Shelf: In this area the parts are stored in bins on static shelving with overstock on top, which is visualized in Figure 4-4. On the first floor of the warehouse there are five aisles in total, named: D, M, F, G and H. These aisles have different sizes again and are able to store a different amount of parts. The second and third floor of the warehouse also consist out of five aisles. The total amount of shelf places is around 9000. Within these aisles Trioliet makes use of bins and drawers, but there are also some locked shelves with parts present. Some parts are solely used for spare parts or production, but most of the parts are used for both processes.

Production: Lastly, some parts come from production. Most of these parts are present in the warehouse already, but sometimes these parts must be picked out of production. Those parts are usually products that are (partly) produced in production and not brought to the warehouse yet or just located in production (parts that are sold less than 12 times a year by spare parts).

4.3.2 Storage policy

In 2015 the new warehouse was built and the layout of this warehouse has been determined. The old warehouse was emptied and all the stored parts were placed in the new warehouse. There was no theoretical or mathematical model used to come up with this layout. However, the layout is not completely random. Trioliet used a prepared plan for the layout of this new warehouse.

Within the pallet area, pallets are located for part picking and for temporary storage. The pallets that are used for picking parts are mostly placed in the first aisle: Aisle C. Trioliet also tries to place parts that are needed for the same machine close to each other. The pallet racks are nine layers high, where the parts that are needed for part picking are especially stored in the lower layers.

For the shelving area, in total three different floors are in use. Each floor consists out of shelves. The parts that are needed the most are placed on the ground floor such that usage of the stairs is minimized. Furthermore the parts are sorted based upon their need for production at the picking zone for production. Parts that are mostly used for spare parts are placed at the other side of the shelving area. Moreover, Trioliet grouped products that are needed together close to each other. An example of that are the stickers, because lots of stickers are used for one production order.

FIGURE 4-4, SHELVING AREA

Once a year the list of ordered parts is checked. When parts that are ordered in high amounts are located at the second or third floor, these parts are moved towards the ground floor. The same holds for the parts in the pallet racks. When parts are currently placed on the third floor, but high amounts are ordered, these parts are moved towards a lower location. Which is again closer towards the ground floor and the picking location.

4.4 Picking of orders

Within this section, first the different orders that are handled at Trioliet are explained. This is followed by the picking policy that is used.

4.4.1 Orders

There are four kind of orders at Trioliet: spare parts, external warehouse, suppliers and production. They are all discussed in the following paragraphs:

Sales spare parts: These orders arrive from the spare parts department. This department receives a phone call or email from a customer and creates an order. These orders are often relatively small. For these kinds of orders, Trioliet guarantees a next day delivery. Thus it is important that these orders (when ordered before 04:00 pm) are shipped on the same day.

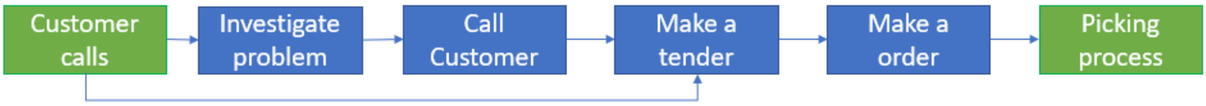

FIGURE 4-5, FLOWCHART SPARE PARTS

External Warehouse: Recall that Trioliet has two external warehouses: one in China and one in the United States. These warehouses are supplied by the warehouse in Oldenzaal. There is no next day delivery arrangement, resulting in more time to pick and pack the orders for these external warehouses. These orders are picked and packed by the operators at the spare parts I/O point. There are also so called 'year-orders' from large customers. For these orders there is again no next day delivery required. The year-orders are seemingly large and acquire almost the same characteristics as an order from the external warehouse.

Suppliers: Trioliet makes use of different suppliers that manufacture semi-finished products. These orders are picked and packed at incoming goods I/O point. These orders are less important within this research, because it is mostly about full pallet loads.

Production: There are two different systems for parts that ought to be moved from the warehouse to production. For some parts they use a push system and for other parts a pull system is used. All parts for production are picked at the incoming goods I/O point. The push and pull systems are explained a little more:

Push: A lot of commonly used parts are located in the production area. The restocking of those parts is done via the warehouse. For this restocking, a two-bin system is used. When a bin is empty, the warehouse is responsible to restock that bin. Checks within production for empty bins is performed on a daily basis.

Pull: The parts that are needed for the assembly of the machines are partly delivered from the logistic center. Production sends an order towards the warehouse. The warehouse picks the orders and brings it to the designated location. After delivery, the order needs to be registered as a production order.

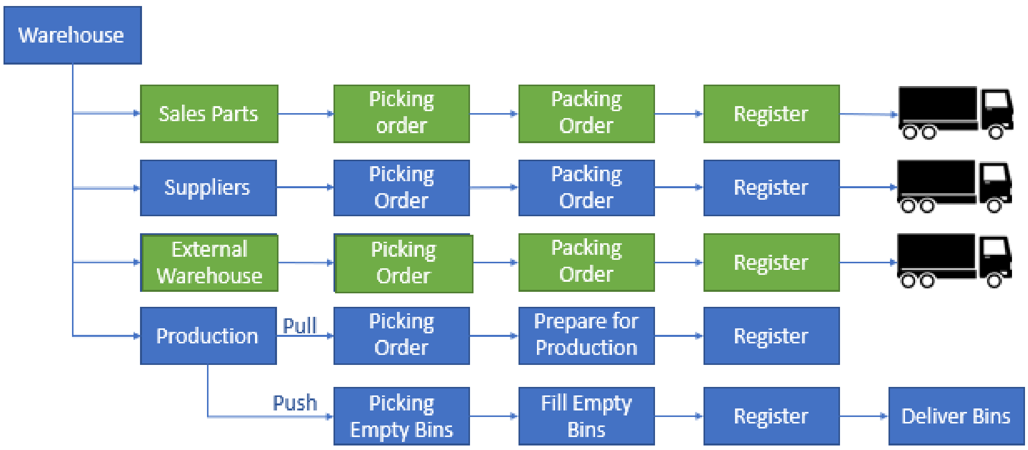

FIGURE 4-6, FLOWCHART ORDER PICKING

4.4.2 Picking policy

As described in Section 4.3.1 there are two different I/O points for the operator, depicted in Figure 4-7 as locations 6 and 7. The operator starts at location 6 when it concerns an order for a supplier or an order for production. The operator starts at location 7 when it concerns an order from the external warehouse or from spare parts. The different policies for these orders are discussed in the following paragraphs.

External warehouse: These orders are usually relatively large consisting of a lot of different parts. All these parts are collected at location 7. When collected they are put in a pallet. Within these orders, varying parts of both the pallet area and the shelving area are present. At the time that the warehouse has been built the green locations were created for temporary storage. But currently they are occupied with storage racks.

For these orders they use order and part picking. Some parts are combined and some parts are picked one by one. A cart is used to bring the parts to the packing table and when needed a reach truck or forklift is used to pick a part from a pallet rack.

Sales spare parts: These orders can be packed both in a box or in a pallet. This is dependent on the size of the components. The orders for the spare parts are also picked and packed at location 7. When it concerns a box, it is packed at location 7 and moved to location 8 for shipment. If it concerns a pallet this can be packed at location 7 or somewhere near the green blocks.

For these orders Trioliet makes use of order and part picking, dependent on the size. Some parts are picked one by one and some parts are picked together.

Production: There are two different orders from production, both picked from location 6.

Push: This encompasses the bins that are refilled with a two-bin system. An operator from incoming goods drives through production and picks the empty bins. The empty bins are refilled at location 6 and located on a pallet. At the end of the day the pallet with full bins goes back to production for replenishment purposes.

Pull: In here the orders for the production of new machines are acquired. The incoming goods department receives an order and picks the parts. All the parts are put in a pallet and when ready sent to production. Order and part picking is used to pick all the parts.

Supplier: This concerns parts that are temporarily stored in the warehouse and need additional editing before it is used within Trioliet. These pallets are assigned to a temporary location until they are sent to the supplier. The supplier processes (for example painting or coating) these products and sends them back to Trioliet.

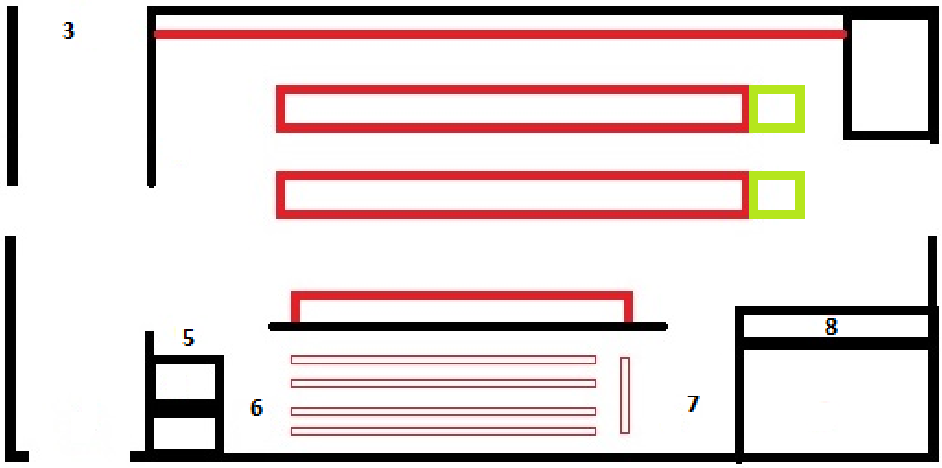

FIGURE 4-7, MAP LOGISTIC CENTER

4.5 Color coding

Within Trioliet different colors are used for different kind of parts. The colors are used to indicate the kind of product and the location of that product. There are five colors used at Trioliet namely: green, yellow, blue, red and gray. The different colors and their usage are discussed below:

Green: These parts are located in the warehouse. When these parts are needed for production, the warehouse picks the parts and makes them ready for transport to the production hall.

Yellow: These parts are located within the production area. These parts are sold less than 12 times a year by the spare parts department. When a part is needed, the parts are picked from production.

Blue: These parts are stored in production and in the warehouse. The parts are delivered and filled by an external supplier. When the stock is low, the bin is automatically restocked by the supplier.

Red: These parts are also stored in production and in the warehouse, but the restock and purchase is done by Trioliet. As explained earlier, Trioliet makes use of a two-bin system to refill the stock both in production and in the warehouse.

Gray: These are one-time products that are located at production. These products do not have a fixed storage location.

4.6 Conclusion

In this chapter the layout and the different flows of the parts are discussed. The warehouse is located in the new logistic center. In the warehouse two different storage options are present: pallet racks and shelves. The large parts are stored in the pallet racks and the shelving area is used for smaller parts. There are four different kinds of orders in the warehouse; orders from suppliers, external warehouse, production or spare parts. The warehouse consists of two picking location (I/O points). At location 6 the orders from suppliers and production are handled, whereas at location 7 the orders from the external warehouse and spare parts are handled. The layout of the warehouse is not random, but also no mathematical or theoretical model has been used to come to this layout. They have tried to put the parts close to the picking location and group parts that are often in the same order. At the end of the year Trioliet checks if there are parts located wrongly and translocate them.

Chapter 5 - Literature review

This chapter provides answers to sub question 2: "Which methods for storage of parts and picking of orders are available in literature". In Section 5.1 the principle of Kanban is discussed, because Trioliet partly makes use of Kanban at this moment. Besides that, Section 5.2 concerns the different lay-out options. Within Section 5.3 possible storing of item policies are discussed. Furthermore, in Section 5.4 possible picking policies are evaluated. Moreover, Section 5.5 describes the forward picking area. Lastly, within Section 5.6 the 'goods-to-picker' automatization options are described. This chapter starts with a small introduction based upon literature.

The processes in a warehouse can be divided into inbound and outbound processes. In between these two processes the products are stored in the warehouse. The inbound processes concern receiving and put-away, whereas the outbound processes focus upon order-picking, packing and shipping. Most of the expense in a typical warehouse is in labor, most of that is in order-picking and most of that is in traveling (Bartholdi & Hackman, 2017). The critical issue is to simultaneously reduce the cost and increase the speed of the order picking activity (Petersen, 1999). According to Coyle (1996): "order picking constitutes 50-75% of the total operating costs for a typical warehouse" (Coyle, 1996). Bartholdi and Hackman (2017) claim that order-picking accounts for about 55% of warehouse operating costs; and order-picking itself may be further broken into traveling, searching, extracting and paperwork (Bartholdi & Hackman, 2017). How this is divided according to Bartholdi and Hackman (2017) is shown in Table 5-1. The order picking process is responsible for most of the operating costs and traveling is the most time-consuming part of the order picking. Because of that, different aspects that are interesting regarding the traveling and the order picking process are discussed.

Activity	% Order-picking time
Traveling	55%
Searching	15%
Extracting	10%
Paperwork and other activities	20%

Table 5-1, Order picking time (Bartholdi & Hackman, 2017)

5.1 Kanban

Currently the Kanban system is used for the floor stock. The Kanban system is developed by the Vice-president of Toyota Motor company, the name Kanban comes from the Japanese words "kan" which means visually and "ban" which means card or board. The basic idea of Kanban is that each workstation reproduces that what the subsequent (i.e. downstream) workstation has consumed (Lödding, 2009). "It is a production control system for just-in-time production and making full use of workers capabilities. Reasons to use Kanban instead of computerized systems are: reduction of processing cost, rapid and precise acquisition facts and limiting surplus capacity of preceding shops" (Sugimore, Kusunoki, & Cho, 1977).

At Trioliet they make use of the two-bin Kanban system for the regulated stock, both in production and in the shelving area. Whereas two-bin Kanban is having normally two unequal sized bins, Trioliet makes use of the two-equally-bin system. According to Kanet and Wells this two-equally-bin Kanban system is widely adopted (Kanet & Wells, 2018). An example of this can be found in the Oracle Corporation's support literature for their worldwide MRP users (Oracle, 1996). Another example is the case study by Childerhouse et al (Aitken & Towill, 2002). This simple system has two bins with an empty bin signal, the empty bin is refilled and the other bin is used to satisfy the demand (Hill, 2012)."The 2-equal-bin interpretation eliminates the need to refill the reserve bin each time a replacement is received. We simply continue using the bin in use until it is empty. Here the order quantity and reorder point are identical, so when a delivery arrives, the container in which it arrives can automatically serve as the second bin (Kanet & Wells, 2018). A two-bin system is typically adopted for parts that are low in cost in combination with a lean concept (Wanitwattanakosol, Attakomal, & Suriwan, 2015). "It is widely popular because it requires no sophisticated information system and no perpetual inventory record keeping, and is consistent with the fundamental principles of Just-In-Time (JIT): it is simple, functional and visually intuitive (Kanet & Wells, 2018). A disadvantage of this two-bin system is that each bin requires twice the period demand of cycle stock (Mills, 2015).

5.2 Lay-out

An important aspect in a warehouse is the lay-out. The traditional warehouse is a warehouse with long straight aisles. This type of warehouse minimizes the building costs and maximizes the storage space. “Unfortunately, designing a storage area exclusively to maximize storage density ignores the operational cost of retrieving items from the space. For example, sacrificing a bit of storage density may allow a design that reduces the cost of retrieving items” (Meller & Gue, 2009). A commonly used alternative is the traditional warehouse with cross-aisles as depicted in Figure 5-1. A cross-aisle is an aisle which is perpendicular to the storage aisles in which the items can be picked. A cross aisle crosses the pick aisles (ERIM, 2018). The main advantage of cross aisles is that they enable savings in travel times, by introducing flexibility in going from one main aisle to the next (Ertek, Incel, & Arslan, 2007). A disadvantage is the sacrifice of some storage places. The cross-aisle as explained is a pretty well-known lay-out, but there are countless other lay-out options to minimize the picking time. In the article of Gue and Meller (2009), the Flying-V, Fishbone, Chevron and combinations of these designs are discussed (Meller & Gue, 2009). These designs are focusing on minimizing the expected travel distance to a single pick. However, other factors like building costs, storage density and user-friendliness are important factors to consider as well.

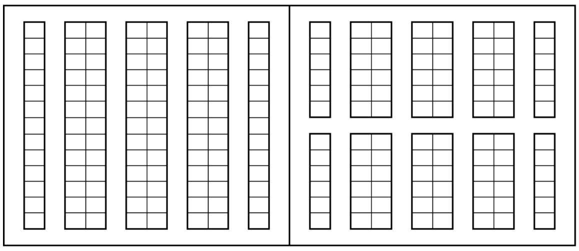

Figure 5-1, Traditional warehouse VS cross-aisles

5.3 Storing parts

Within this section, the different storage strategies are discussed. A storing strategy concerns the allocation of stock keeping units (SKUs) to storage locations by making a link between an item and a location. At first there are two basic slotting strategies: random and dedicated.

Random storage means that any location in a warehouse can be chosen. On the other hand with dedicated storage an SKU is coupled at a specific location. The random storage policy is widely used in many warehouses because it is simple to use, often requires less space than other storage methods, and results in a more leveled utilization of all picking aisles (Petersen, 1999). On the downside this may result in longer travel times (Kofler, Beham, Wagner, Affenzeller, & Achleitner, 2011).

Dedicated storage is based on the idea that fast-moving items should be located in easily accessible areas. There are different dedicated storage policies available. A slotting strategy that is often used is based on the cube per order index (COI). The adoption of COI-based storage policies is generally a more `information intensive’ approach than random storage, since order and storage data must be processed in order to rank and assign items by decreasing COI (Caron, Marchet, & Perego, 1988). The COI-based storage policies tend to concentrate on picking operations in the area dedicated to items with a low COI (Kallina & Lynn, 1976). These slotting strategies seem optimal in a single-command transaction. In contrast, when an order has multiple items and all these items must be picked in one tour, COI is not optimal anymore. In the article of Mantel, Schuur and Heragu (2007) a solution for a multi-command transaction has been described, which is named Order Oriented Slotting (OOS) (Mantel, Schuur, & Heragu, 2007). The idea of OOS is to store items that appear often together in an order close to each other in such a way that the total time needed to pick all the orders is minimized. If the number of SKUs per order is very small, a strategy like OOS does not have much effect. Because in this case the COI approach performs well enough (Mantel, Schuur, & Heragu, 2007).

There is also a combination of random and dedicated storage, which is called class-based storage. Class-based storage means that items are divided into classes based on their pick frequencies. The storage locations are divided into zones and each class is assigned to a zone such that the fast moving classes are closest to the depot. Within a class no further distinction on pick frequency between items is made. It is convenient to implement and maintain, easy to handle assortment changes or changes in pick frequency and often lead to a substantial reduction in order pick travel distance compared to random storage (Le-Duc & de Koster, 2005).

5.3.1 Cube per Order Index (COI)

The cube per order index is a widely used rule for allocating storage space to inventory items in a warehouse. It concerns the ratio of items storage space requirement to its popularity. The parts are ranked according to their popularity to the most accessible locations (locations close to the floor and close to the I/O point). First of all an introduction of the variables:

q = number of storage locations
n = number of SKUs
m = number of input/output (I/O) points
S_j = number of storage locations required for SKU j
T_j = number of trips in/out of storage for SKU j per period, that is, throughput of SKU j
p_i = percentage of travel in/out of storage to/from I/O point i
d_{ik} = distance required to travel from I/O point i to storage location k
x_{jk} = 1 if SKU j is assigned to storage location k; otherwise, 0
$f(x)$ = average distance traveled

The integer linear programming model can be modelled like this:

Min $z = \sum_{j=1}^{n} \sum_{k=1}^{q} \frac{T_j}{S_j} f_k x_{jk}$

s.t.

$\sum_{j=0}^{n} x_{jk} = 1$ k = 1,.....,q (1)

$\sum_{k=0}^{q} x_{jk} = S_j$ j = 1,......,n (2)

$x_{jk} = (0,1)$ ∀ j, k (3)

The first restriction ensures that one and exactly one product is assigned to a storage location. Restriction two ensures that the assigned storage locations match the required number of locations.

The problem corresponds to a form of a balanced transportation problem. It has been assumed that: $q = \sum_j s_j$. For the problem to be feasible, it must hold that $q \geq \sum_j S_j$. If $q - \sum_j S_j > 0$, the previous balanced formulation is obtained by introducing a fictitious SKU 0, with $S_0 = q - \sum_j S_j$ and $T_0 = 0$.

In most warehouses there are more storage locations than product types. The above transportation problem can be solved to optimality by using the following solution method:

Compute: $f_k = \sum_{i=1}^{m} p_i \, d_{ik}$

Renumber locations by: $f_1 \leq f_2 \leq \cdots \leq f_q$

Renumber SKU by: $\frac{T_1}{S_1} \geq \frac{T_2}{S_2} \geq \cdots \geq \frac{T_n}{S_n}$

With the solutions method above, Heskett (1963) introduced the Cube-per-Order-index (COI): $COI_j = \frac{S_j}{T_j}$ (Heskett, 1963):

- The COI-index is calculated for each product and the values are sorted in increasing order.
- Locations are classified according to the distance to the I/O point.
- Products with the lowest COI-index are placed at the 'best' location.

5.3.2 Order Oriented Slotting (OOS)

Mantel, Schuur and Heragu (2007) introduced a slotting strategy that is based upon multi-item orders instead of individual location visits. OOS is a slotting strategy for which the way of allocating parts to a location is directly related to the way of calculating actual travel times. SKUs that occur often together in an order are located close to each other, to be able to minimize the total travel time. For the algorithm, we need to make use of two important variables:

- f_{io} = popularity, number of orders that require product i
- f_{ij} = interaction frequency, number of orders that require product i and j

The authors argue that SKUs that are frequently ordered together should be located close to each other, while popular SKUs should not be located far from the depot.

An integer linear programming model can only be solved to optimality for a moderate size warehouse, so two new heuristics are proposed for the slotting problem. The interaction frequency heuristic and the interaction frequency based quadratic assignment heuristic.

The interaction frequency heuristic is a constructive heuristic which consists of the following steps:

1. Allocate the singles via their COI-allocation.
2. Sort the interaction frequencies f_{ij} (>0) in descending order.
3. Allocate item i and j as closely together as possible accounting their COI and determined slack.
4. If for i and j no suitable location is available, then process next interaction frequency.
5. Allocate, after processing all interaction frequencies, the items that have not been allocated so far.

The interaction frequency based quadratic assignment heuristic is also a constructive heuristic. The slotting problem is formulated as a form of quadratic assignment problem (QAP):

The integer linear programming model can be modelled like this:

$$min_{a\epsilon S} Z(a) = \sum_{i=1}^{I-1} \sum_{J=i+1}^{I} f_{ij} d_{ij}(a) + a \sum_{i=1}^{I} f_{i0} d_{i0}(a)$$

- $d_{ij}(a)$ = Routing policy specific distance between product i and j
- $d_{io}(a)$ = the distance between product i and the I/O point
- α = Relative weight to the objective of placing items near the I/O point
- S = Set of all the storage assignments

The heuristic minimizes z over S. The value of α has to be determined empirically in order to obtain a correct balance between the two terms. Because the QAP is NP-hard, only small instances can be solved to optimality within a reasonable amount of time. For large instances, heuristics ought to be put in place.

The author provides a small numerical example to show that the OOS performs better in this case than the COI-rule, depicted in Figure 5-2. For the COI all four orders are disjoint and located based on the frequency of picks. Note that in the example the four orders are disjoint. Hence, one might hope to improve the above COI-approach by treating each order as if it is made up of only one SKU which occupies a number of locations equal to the order size. This results in a total travel distance reduction of 16%, from 162 to 136.

FIGURE 5-2, COI VS OOS (MANTEL, SCHUUR, & HERAGU, 2007)

5.4 Picking items

The picking process encompasses retrieving products from storage in response to a customer request. A customer order can be picked by one worker or by many workers at once. There are different picking strategies that are optimal in certain situations. The different picking strategies that are discussed here are: (1) picking by order, (2) cluster picking, (3) batch picking, (4) zone picking and (5) wave picking. "The appropriate strategy depends on many things, but one of the most important is how quickly must orders flow through the process. For example, if all the orders are known before beginning to pick, then we can plan efficient picking strategies in advance. If, on the other hand, orders arrive in real time and must be picked in time to meet shipping schedules then there is little or no time in which to seek efficiencies" (Bartholdi & Hackman, 2017). The first two picking policies are serial (by a single worker at a time) and the other policies are parallel (by multiple workers at a time). The general trade-off is that picking serially can take longer to complete an order but avoids the complications of coordinating multiple pickers and consolidating their work (Bartholdi & Hackman, 2017).

Picking by order: This is the most simple and standard option. The picker takes one order and travels through the warehouse collecting all the items until everything of that specific order is picked. Picking by order is not the most efficient option, but it is the easiest policy. When picking individual orders the minimum amount of handling is involved (Richards, 2011). The advantage of strict order picking is that order integrity is maintained, avoids rehandling and fast service when customers are waiting for their orders (Peterson, 2009).

Cluster picking: In order to reduce overall travel time, operators can take a number of orders out into the warehouse and pick into individual compartments on their trolleys or cages (Richards, 2011). The picker returns when everything of all the orders is collected. This picking policy is easy in use because the picker can just focus on his/her own orders.

Batch picking: With this policy, operators pick products for a number of orders at the same time. The orders are broken down in their constituent products and new picking lists are created. Batch picking generally results in less travel time per SKU. However, order integrity is lost, and the potential for errors increases (Peterson, 2009).

Zone picking: Within this policy operators are divided amongst different picking zones. Operators are responsible that everything within their zone is picked. Due to the smaller area coverage by each picker, the advantages of zone picking are the familiarity of each picker with his zone and the travel time reduction (Jane & Liah, 2005). The disadvantage is that there is a lot of communication needed and finding the right division of zones is difficult.

Wave picking: Each picker picks continuously during a wave, where the next wave does not begin until the operators have completed the first wave. The waves can be classified dependent on length of time, importance or time until shipment. "Wave picking has the same advantages as batch zone picking. However, wave picking requires a picker to pick an SKU only once per wave, permitting even greater volume picking. The drawbacks to wave picking include those mentioned for batch zone. In addition to the disadvantages of batch zone, wave picking requires more time and space for order consolidation because waves contain more orders than batches" (Peterson, 2009).

5.5 Forward pick area

The forward pick area can be seen as a warehouse within a warehouse. The most popular SKUs are stored in small amount in the forward pick area, such that SKUs that are required often can be concentrated within a small area. "This reduces unproductive travel by order pickers and enables closer supervision (Bartholdi & Hackman, 2008). With as result reduction of picking cost and increase of responsiveness of customer demand (Schuur, 2018). The trade-off is that the forward pick area must be replenished from a bulk storage or reserve area elsewhere in the warehouse (Bartholdi & Hackman, 2008). Because of this forward pick area, restocking is introduced. Replenishment is performed from the reserve area. Replenishing results in extra time and costs more money. Extra space is required to be able to make use of a forward pick area. The basic issue in the design of a forward-pick area is: Which SKU to store in fast-pick area and how much of each SKU to store in the fast-pick area. To answer these questions, Bartholdi and Hackman (2017) created a fluid model. More information about this fluid model can be found in their book: 'Warehouse & Distribution' (Bartholdi & Hackman, 2017).

5.6 Automation

In Section 5.4 different order picking strategies are discussed. These order picking strategies are all 'picker-to-goods' strategies. In here, the 'goods-to-picker' options are discussed. Goods-to-picker systems are designed to keep the operator working as much as possible and reduce the amount of travel time (Richards, 2011). The introduction of a 'goods-to-picker' system will make substantial efficiency savings in the way they handle, store and retrieve inventory (Kardex Remstar, 2018). The focus of this section is upon the shelves area, because the parts in the pallet racks are difficult to automate due to their weight, size and shape. First of all, several generic disadvantages of automation are listed. Where on the other hand the advantages that come along are also evaluated.

Disadvantages of automation according to Richards (2011) are:

- "High opportunity cost: could the investment have been spent more effectively elsewhere?
- High investment cost: building, equipment, information technology.
- System failure operations are entirely reliant on technology.
- Anomalies are not accepted and need to be handled separately.
- Standardized unit loads required.
- More quality control is required on intake.
- High cost of disposal of equipment.
- Lack of flexibility" (Richards, 2011).

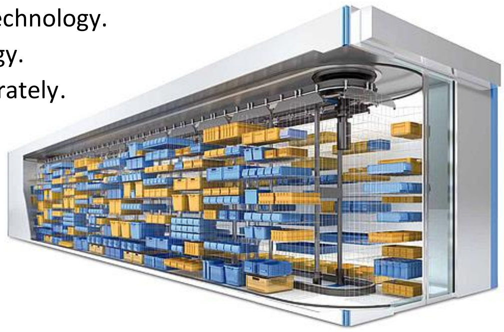

FIGURE 5-3, HORIZONTAL CAROUSEL (SCHUSTER, 2018)

Horizontal carousel

A horizontal carousel as depicted in Figure 5-3 works on a similar principle as a merry-go-round. The carousel can be made up of bins or other storage equipment. An operator types the location or product number and the carousel starts turning. When the right product is achieved, the carousel stops. Horizontal carousels are ideal for storing and picking individual items, medium to large cartons and products including hanging garments (Richards, 2011). Because they carry products to the picker there is no need for the picker to walk along an aisle and thus carousels can be packed tightly, which increases space utilization (Bartholdi & Hackman, 2002).

Vertical carousel

As a horizontal carousel moves the items in horizontal direction, a vertical carousel as depicted in Figure 5-4 moves the products in vertical direction. Similar as the horizontal carousel, the vertical carousel brings the requested item to the operator. They allow you to use the maximum height available within the building, providing the best use of space within a very small footprint (Richards, 2011). Another advantage is that the load comes to the right height, so that the handler can pick as close to the load as possible and minimize lifting (Link 51, 2016).

FIGURE 5-4, VERTICAL CAROUSEL (SCHUSTER, 2018)

Vertical Lift module

A VLM (vertical lift module) works similarly as an elevator. The operator indicates the location or product number and the VLM brings the requested item to the operator. A VLM makes use of the maximum height of the building and makes best use of space. There are many similarities between the vertical carousel and the VLM, but there are also some differences. "The VLM is more suitable for highly variable sizes and weight storage parts, frequently changing inventory mix and heavy items that require lifting assistance for the operator to safely handle. Where the vertical carousel is more suitable for storing parts sharing relatively similar dimensions and items that can be hand-picked without lift assistance" (Dube, 2018).

5.7 Conclusion

Within this chapter a broad literature review is conducted. This review started with the Kanban system that is currently in use at Trioliet. Furthermore, the different aspects of storing and picking policies are evaluated. First of all, the lay-out of a warehouse is discussed. A different layout can result in less travel time, but on the other hand the building costs might increase drastically. Another aspect that is important to take into account is the total storage space within a warehouse. Furthermore, the traditional warehouse with corresponding cross-aisles is explained here.

Furthermore, the storing of parts is discussed. Trioliet currently does not make use of a mathematical or theoretical model to allocate the different parts to a specific location. Multiple storing strategies are discussed. Regarding dedicated storage, the principles OOS and COI are explained. Besides the dedicated storage, the aspects of class-based and random storage are described. Moreover, the five strategies proposed for the picking of parts are evaluated: (1) picking by order, (2) cluster picking, (3) batch picking, (4) zone picking and (5) wave picking. The corresponding pros and cons per strategy are evaluated and the strategies are compared with each other.

Lastly, the matter of automation is discussed based upon literature. Within literature, three possible automation options to attain goods-to-picker processes are found. The ones that are explained throughout this chapter are the horizontal carousel, the vertical carousel and the vertical lift module.

Chapter 6 - Current performance and bottlenecks

As described in Chapter 4 there are different steps within the picking process. In this chapter these different steps are analyzed to come to an answer on the third research question: "What are the root causes for the long order picking times". On the basis of four sections and an introducing section the causes are explained. Within Section 6.1 the bottlenecks are introduced. Furthermore, in Section 6.2 the inefficiency within the receiving process is discussed. Moreover, in Section 6.3 the set production at Trioliet is discussed. Whereas in Section 6.4 the storage policy is discussed. Throughout Section 6.5 the order picking process is analyzed and evaluated. Lastly, in Section 6.6 the storage system of small parts is discussed.

6.1 Introduction

Currently there are no KPIs within Trioliet that are suitable for exposing the bottlenecks regarding the problem statement. KPIs that are needed in this research must indicate waste that results in inefficiency. The first step is to define the bottlenecks in the current situation. The second step is to measure the performance and calculate the KPIs related to the bottlenecks.

The bottlenecks in the current situation are exposed by observing the process, analyzing the data and by doing interviews with the employees of Trioliet. During this process a mind map is created. This mind map is depicted in Appendix A.

With the information from the mind map the following five possible bottlenecks are investigated:

Possible bottleneck 1: *Inefficiency within the receiving process*. Several problems in the receiving process were noticed through observations and information from the employees. The receiving area is fully occupied almost every day, which results in significant problems in the receiving area. By solving this problem the efficiency can be improved in the receiving process. This possible bottleneck is further analyzed in Section 6.2.

Possible bottleneck 2: *The set production is inefficient*. At Trioliet there are a lot of parts that are sent as a set. These sets are assembled at the spare parts department. Assembling is done manually at this moment and during the picking and packing of these sets there are some inefficiencies. By solving these, the set production of Trioliet can become less time-consuming. This possible bottleneck is further analyzed in Section 6.3.

Possible bottleneck 3: *The storage strategy is not optimal*. Currently Trioliet is not using a storage strategy. They tried to locate the parts in an efficient way, but no theoretical or mathematical model is and has been used to locate the parts. If the parts are not stored optimally it can result in long travel time and distance. This possible bottleneck is further analyzed in Section 6.4.

Possible bottleneck 4: *The order picking process is not optimal.* Order picking is currently done by the 'picking-by-order' process. For the heavy and difficult to handle parts that are located in the pallet area, parts picking is used. Currently a cart is used to pick the parts. The order picking process at Trioliet is a time-consuming process which results in inefficiencies. This possible bottleneck is further analyzed in Section 6.5.

Possible bottleneck 5: *The storage system for small parts is not optimal.* Currently small parts are located in the shelves. Trioliet uses shelves with eight layers. A lot of ground space is needed to locate all the parts. Trioliet has the idea that there is potential for improvement by introducing a goods-to-person principle. This possible bottleneck is further analyzed in Section 6.6.

6.2 Receiving process

The possible inefficiencies in the receiving process is further analyzed within this section. This section starts with a description of the receiving process, depicted in Figure 6-1.

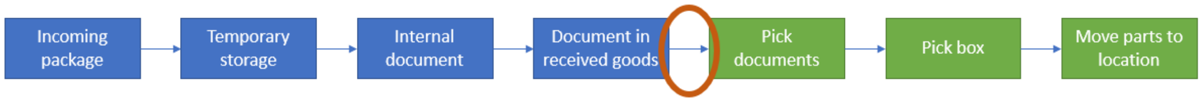

FIGURE 6-1, RECEIVING PROCESS

The process starts when a truck arrives at the logistic centre of Trioliet at location 4 of Figure 6-2. The truck drives to the gate and parks at the unloading dock. The truck is unloaded by an operator and the parts are moved to the temporary storage location depicted at number 5. An internal document is printed and the operator checks the consignment note of the supplier. The documents are put together in the 'incoming good bag' at location 2.

The second part of the process starts when an operator picks the documents. The operator picks the documents and starts searching for the related box or pallet. When the box or pallet is found, the operator starts unloading the box or pallet and moves the parts or pallet to the warehouse location.

A problem that occurs during this process which results in inefficiencies is that one part is performed by one operator and another task is performed by another operator. Which is depicted in blue and green in Figure 6-1. Due to this fact, unnecessary searching time is added to the process as indicated by the red circle in Figure 6-1.

The forklift driver moves the pallets somewhere at the temporary storage location and retrieves the documents. There is no information upon the location of the box/pallet stated on the document. When the operator starts moving the parts from temporary storage to the warehouse, the operator first has to search for the box or pallet that contains the parts mentioned in the document.

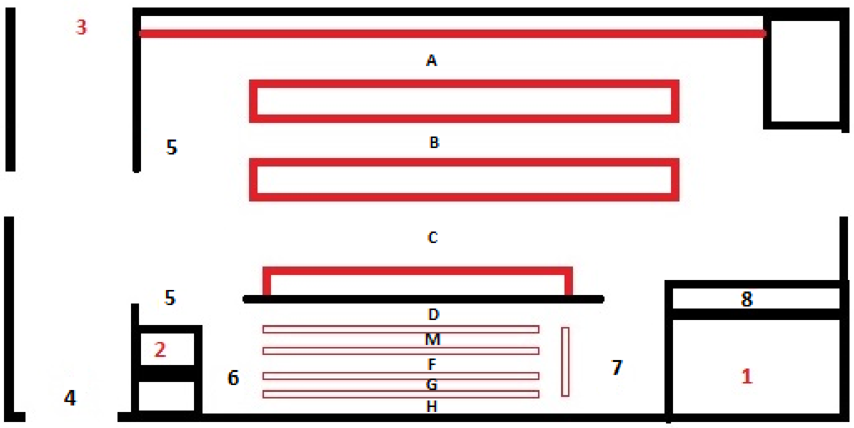

FIGURE 6-2, MAP LOGISTIC CENTER TRIOLIET

Another problem is the lack of space. When a full truck load arrives at Trioliet there is not enough space to locate all the pallets in a logical way. Because of that, the pallets are located throughout the entire temporary storage, which creates unnecessary extra travel time and furthermore increases the searching time. There are also problems regarding the traffic flow, because parts are blocking the way between production and the warehouse.

6.3 Product sets

Within this section the possible bottleneck that the production of sets is an inefficient process is discussed. At Trioliet there are a lot of parts that are sent as a set. The sets are explained and problems during the set production are discussed. This section ends with a small example.

Sets are grouped parts that are always sent together, for example assembly sets or sealing sets. These sets consist of different parts that often are almost the same, like for example rings, bolts or nuts. Usually a bigger part from the pallet area is also part of a set. For example a set with rings, bolts, nuts and a knife for a Triotrac. Currently, there are around 160 different sets at Trioliet with a total demand of 34,601 a year. The idea is that most of the sets are created in advance, such that these sets can immediately be sent when requested. The picking and packing of these sets is completely manual at this moment.

From this total of 34,601, 29,341 are for the sets with a 'trioform knife' in combination with two rings, bolts and nuts. This is a relatively small set and all the small parts needed in this set are located in the fast pick area and the knifes are located at the beginning of the pallet area. Currently the rings, bolts and nuts are located in the fast pick area and are picked when an order comes in. When these sets are needed in large amounts they are sent in sets of 100. In the rest of this report this 'trioform knife set' is excluded and is analyzed separately. This is done because it contributes for almost 85% towards the set production.

The other 5,260 picks are sets that are needed in smaller amounts. From these 5,265 picked sets in total 4,937 sets were needed ten times or more in 2017. These are 73 different sets with an average demand of 68 in 2017. The average number of order lines of these sets is 5.5 and the average parts per order rule are approximately 2.86. The intention is to make these sets in bulk to minimize the travel and handling time, but because the stock is insufficient they are often produced in smaller amounts.

Nine different sets that are clocked are indicated in Table 6-1. The average time to pick and pack a set is 4.33 minutes, which seems long for these particular sets. What is especially remarkable is that set 500328 is taking 16 minutes for creation. This set was needed 46 times in 2017 meaning that (46*16=) 736 minutes are required to pick this set. This set is explained as an example in Section 6.3.1.

In total 21 different sets are clocked with a total amount of 472, shown in Appendix B. The average picking time per set was 3 minutes, with an average of 4.67 different parts per set. For all the sets an average of ((3/4.67)*5.5) = 3.5 minutes is required per set. When multiplying this number for all the sets in this category it takes around (3.5*4,937=) 288 hours a year to produce all the sets.

Set	Amount	Time	Per Set
0500576	40	20	0,50
0500192	10	15	1,50
05949	5	15	3,00
0500451	10	30	3,00
05948	15	20	1,33
0500328	5	80	16,00
01003	5	50	10,00
0500446	50	80	1,60
0500452	40	80	2,00
Average	20	43	4,33

Table 6-1, Clocked sets

The different steps in the set assembling process are depicted in Figure 6-3. These handling steps are discussed in the following sections.

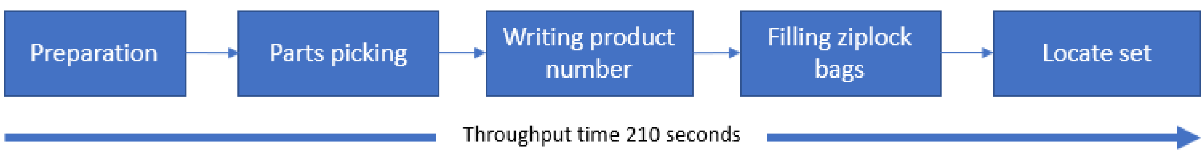

Figure 6-3, Set assembling process

Preparation:

The assembling of sets starts with the preparation phase. The preparation of the sets consists out of picking the documents and the ziplock bags needed for the sets. The documents are printed at the spare parts department and moved to the reception bin. The operator takes the documents and picks the ziplock bags needed for the set. This process is an efficient process and is therefore not analyzed further.

Parts picking:

Parts picking is the second step in the set assembling process. This step starts when the preparation is done. Dependent on the amount of sets needed, the operator picks full bins with parts or counts the parts at their location in the warehouse. A major inefficiency in this process is the travel distance. The travel distance for the different sets is analyzed.

For the 73 different sets, the travel distances are calculated. This is calculated with a tool created by Bartholdi, Tang and Cubbillos (2018). The program relies on the Lin-Kernighan heuristic, which begins with a solution and then searches for small changes that will improve it (Bartholdi, Tang, & Cubbilos, 2018). the Lin-Kernighan heuristic makes an efficient, cost-dependent, breadth-first search for one level and then a depth-first search for a better ʎ-change (Papadimitriou, 1992). The average distance per set is 65 meters, an example of the output is depicted in Appendix C. There are 244 different parts needed in these 73 sets. 32 parts are located at the pallet area and the other 212 parts are located in the shelves. The operator has to walk through the whole warehouse to pick all the parts and has to count the right number to prevent a second walk (to bring the parts back or pick extra parts). Because the parts are divided throughout the entire warehouse the picking times are relatively long. When the operator produces a lot of sets at once, he/she takes the whole bin and brings it back afterwards.

In Figure 6-5, the location of all the parts needed in the sets that are located in the shelving area are depicted. The I/O point is located at the bottom and the locations with spare parts are red. There are five aisles and two cross-aisles. Most of the shelves are eight layers high and picks can be done at the blue lines/positions. The green part of Figure 6-4 is depicted in Figure 6-5. An example of the picking of one set is depicted in Figure-6-6.

When analyzing the figure it is clear that the parts are not located optimally. The part picking process is an inefficient process, because the storage policy for the underlying parts is not optimal. The parts needed in a set are located throughout the entire warehouse, resulting in unnecessary high travel distances.

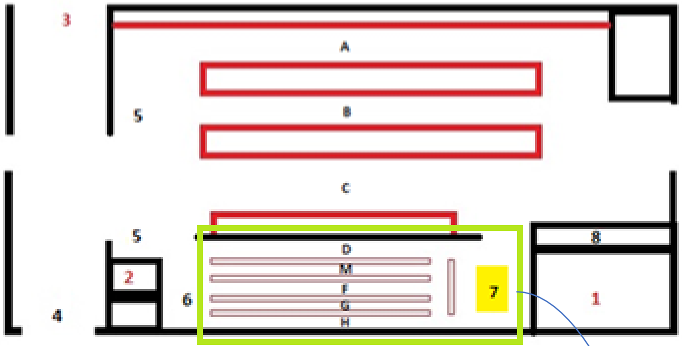

FIGURE 6-4, MAP LOGISTIC CENTER

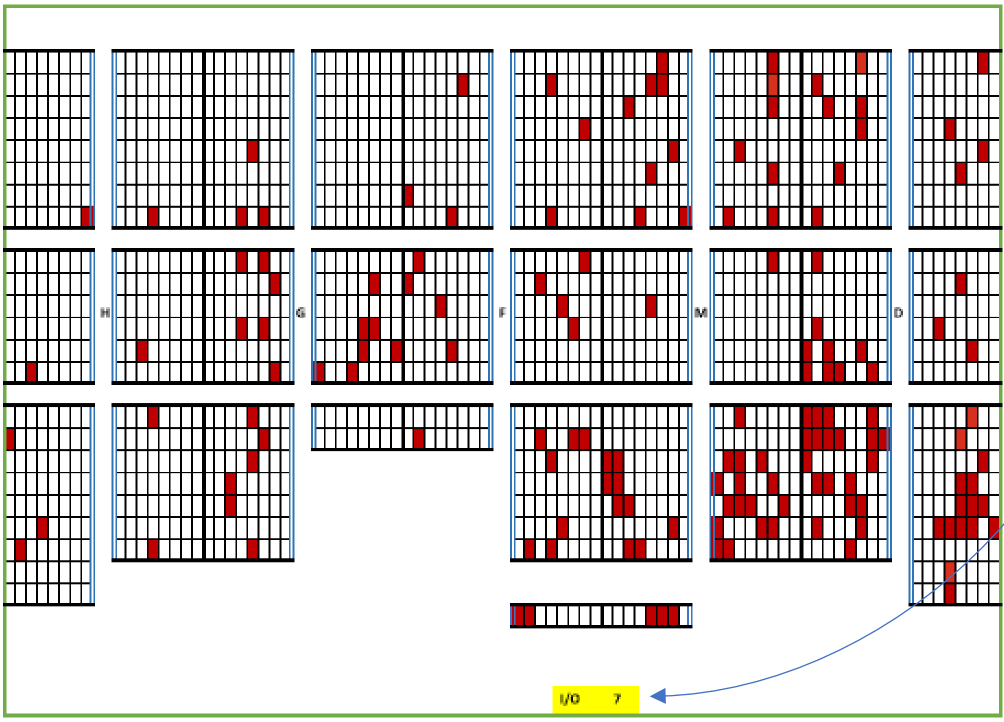

FIGURE 6-5, LOCATIONS OF PARTS

Writing product number:

When all the parts are picked, the packing process can start. The first step in the packing process is writing the product number on the ziplock bags. An operator writes the product number on the ziplock bags and the set number on the final package. Currently the writing is done completely manual, resulting in a time-consuming process. The writing of product numbers takes an enormous amount of time and the handwritten product numbers also provide a rather unprofessional look for Trioliet.

Filling ziplock bags:

All the parts are located on the packing table and the ziplock bags are labeled. The last step in the assembling process is filling the ziplock bags. The operator takes the parts and puts the parts in the labeled ziplock bag. When all the bags are filled, the total set is put in a final package.

Currently this process is also done manually, again resulting in a time-consuming process. The filling of ziplock bags requires a huge amount of time and therefore there is potential for improvement here.

Locate set:

After performing all the above mentioned steps, the set is ready and can be moved to its location in the warehouse. The location of the sets is discussed in Section 6.4.

Another problem in the set production is the matter of having insufficient stock. Batch production will improve the set production, but because of insufficient stock this is not possible. The consequence of this is that the sets are produced in small amounts, therefore having incompetent production. As a consequence the sets are not ready and need to be picked and packed when requested. The operator first has to print a bill of material of the specific set, thereafter the operator has to pick and pack the set. Altogether this requires a significant amount of time, something that is logically not desirable. Especially if an order comes in at 04:00 pm and needs to be sent away the same day.

So overall there are a couple of possible causes for the problems with the sets:

- Long travel times, because the parts within a set are located throughout the entire warehouse.
- All the different components must be packed in separate bags, requiring a lot of time.
- Each ziplock bag needs a handwritten product number, requiring a lot of time to write them all.
- There is no bulk production, because of insufficient stock.

To create a better idea of the set picking and packing process an example is created and explained in the next paragraph.

6.3.1 Example

As an example, the set that takes the longest is chosen. The set that is explained in this example is set 0500328. This set is a conversion box for a 0500330 or 0500331 (these are knives for a Triotrac). This set consists of 22 different components with a total amount of 129 parts. Three of the parts in this set are located in the pallet racks and the rest is located in shelves. In Table 6-2 all the components and the number of parts are displayed.

Part Nr.	Amount	Location
2003828	1,00	0C340B
24153	2,00	0M4205
25624	2,00	0M3702
25636	4,00	0M4100
26167	2,00	0M3406
27228	2,00	0H4103
33031	12,00	0F4904
44130	4,00	0M3703
80816	4,00	0D0605
83921	6,00	0F4904
83934	6,00	0M2902
83937	2,00	0M4101
84808	4,00	0M0505
84925	12,00	0F4903
84942	24,00	0F4903
85008	4,00	0D0406
86810	26,00	0F4903
86812	4,00	0M1001
12413	1,00	0C360C
12414	1,00	0C360A
2001797	2,00	0C32XB
26184	2,00	0F5102
83948	4,00	0F4903

TABLE 6-2, SET 0500328

The picking process starts with picking all the components that are needed for a set. Currently the operator counts the right amount for all parts at each shelf. For example counting 26 parts for the product 86810 and taking them to the worktable. If all the parts are picked then the packing process can start. All the screws and nuts are packed in ziplock bags and the operator writes the part number on each bag. All the ziplock bags are packed together in a box with the parts from the pallet area. Eventually the boxes are sealed.

In Figure 6-6 the shelving area is depicted. There are five aisles and two cross-aisles. Picks can be done at the blue lines/positions. The shelves are nine layers high.

From this figure it can be concluded that the underlying parts of this set are divided over the warehouse. The total travel distance to pick all the parts is 98 meters.

The picking starts at I/O point 7. The operator walks the light green line to pick all the parts. The dark green lines are vertical handlings representing the picking of parts from a higher layer, Figure 6-6.

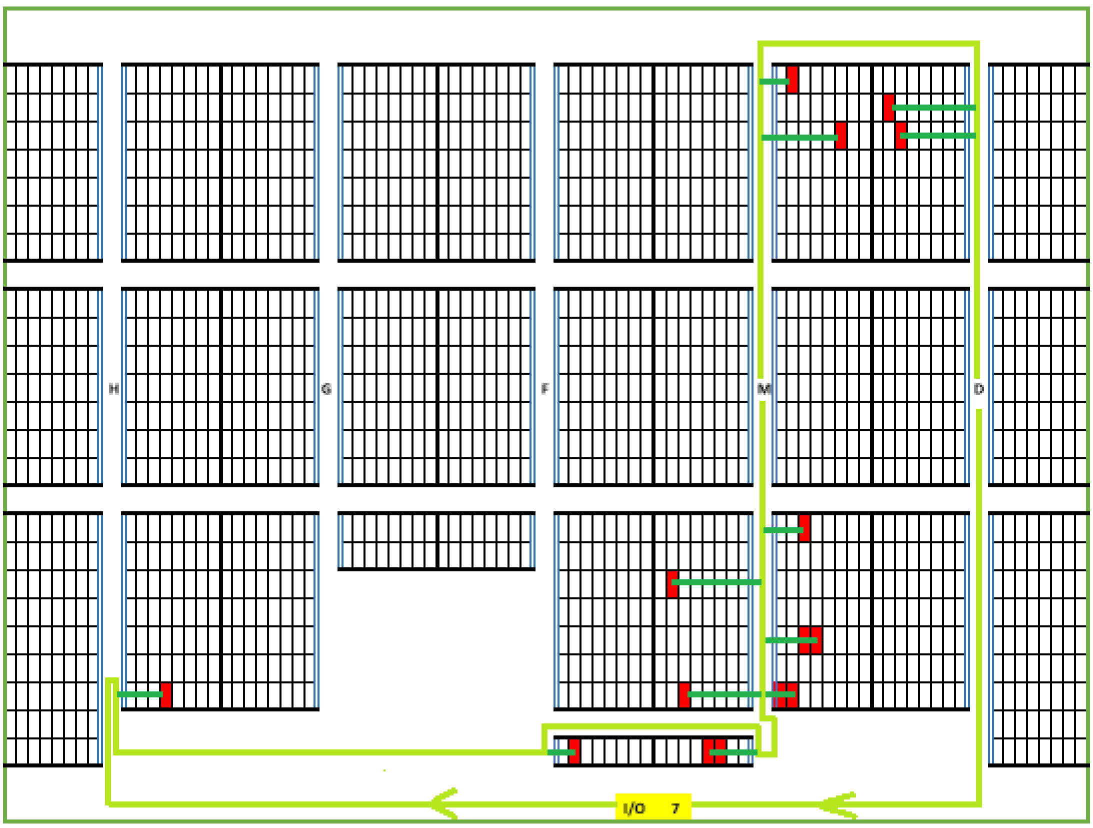

FIGURE 6-6, LOCATIONS OF PARTS SET 0500328

6.4 Storing parts

The expected bottleneck that the allocation of parts is not correct is analyzed in this section. Trioliet has chosen to not use a mathematical or theoretical model to allocate the parts to the locations. In this part the lay-out and the consequences of certain choices are discussed. This chapter ends with a small example as illustration.

As mentioned beforehand, the warehouse makes use of two different picking locations. This has been integrated to separate different flows. In this part the consequences of this choice are discussed. The storage locations are also discussed, where we take a look at the storage location of the parts and their corresponding picking policy.

In this section the two different I/O points are discussed separately. For both I/O points two heatmaps are created, one for the shelving area and one for the pallet area. First the I/O point at spare parts is discussed, followed by the I/O point at incoming goods. According to the studied literature, parts that are often picked need to be located close to the picking location and close to the floor as well.

The I/O point of incoming goods is located at location 6 (Figure 6-7). The I/O point of spare parts is located at location 7 (Figure 6-7).

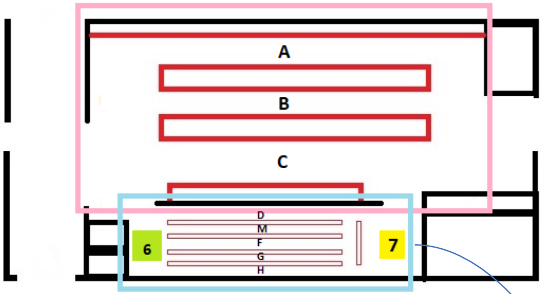

FIGURE 6-7 MAP OF LOGISTIC CENTER

The heatmap for the pallet area is the pink area in Figure 6-7. The heatmap for the shelving area is the blue area in Figure 6-7.

In Figure 6-8 a setup for the heatmap of the shelving area is depicted. This represents the blue block of Figure 6-7.

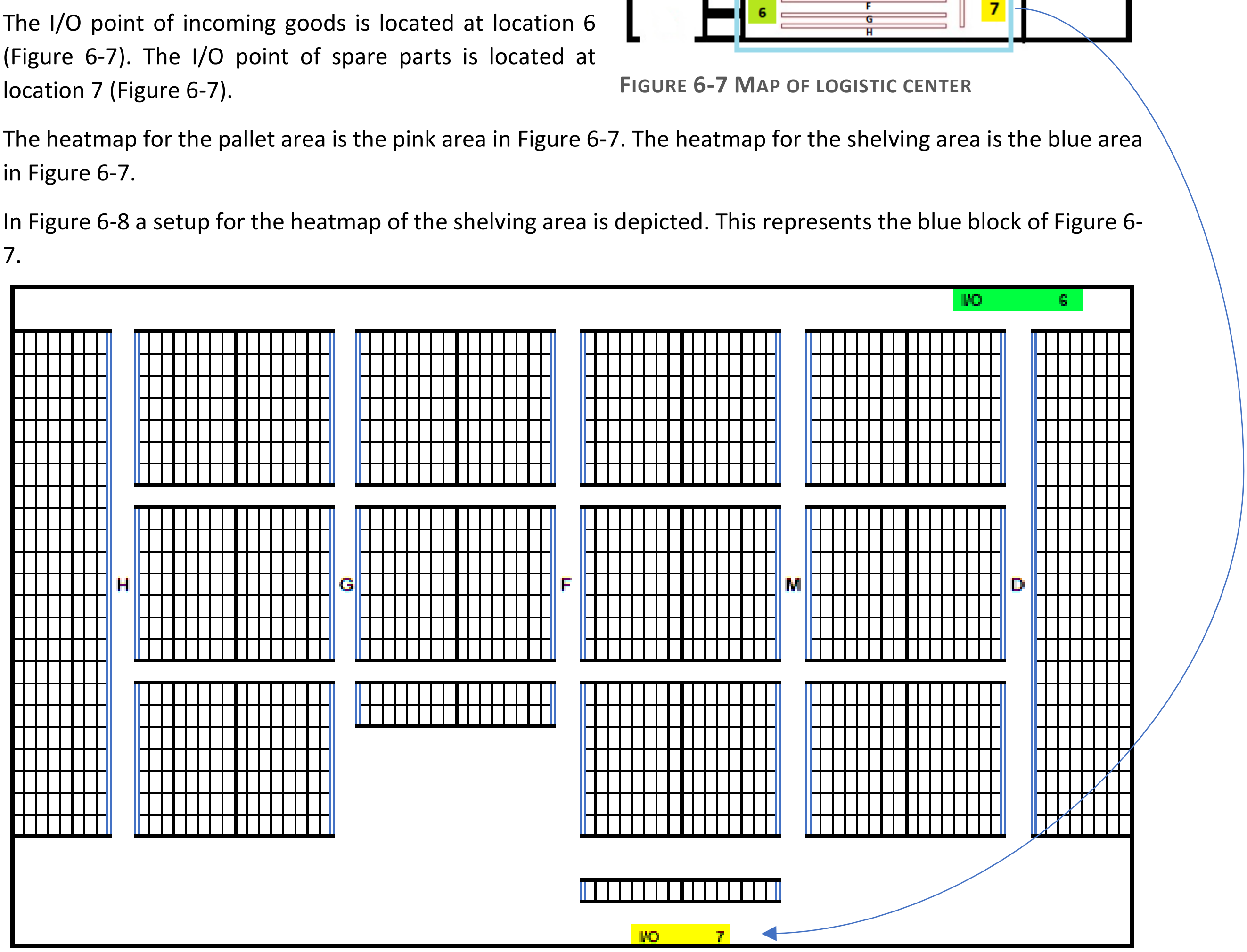

FIGURE 6-8, TEMPLATE HEATMAP SHELVING AREA

In total there are five different aisles (D,M,F,G and H) in the shelving area and two cross-aisles. Most shelves are eight layers high. The I/O point of the spare parts is located at position 7 and the I/O point for the incoming goods is located at location 6. Picks can only be done at the double blue lines/locations.

In Figure 6-9 an example of the visualized pallet area is depicted, this represents the pink area in Figure 6-7. There are three aisles and the racks are nine layers high. The parts can be picked at the blue lines/locations. I/O point 6 is located at the left side of the warehouse, which is the incoming goods I/O point. The other I/O point is located at the bottom right of the warehouse, this I/O point is at the spare parts side of the warehouse.

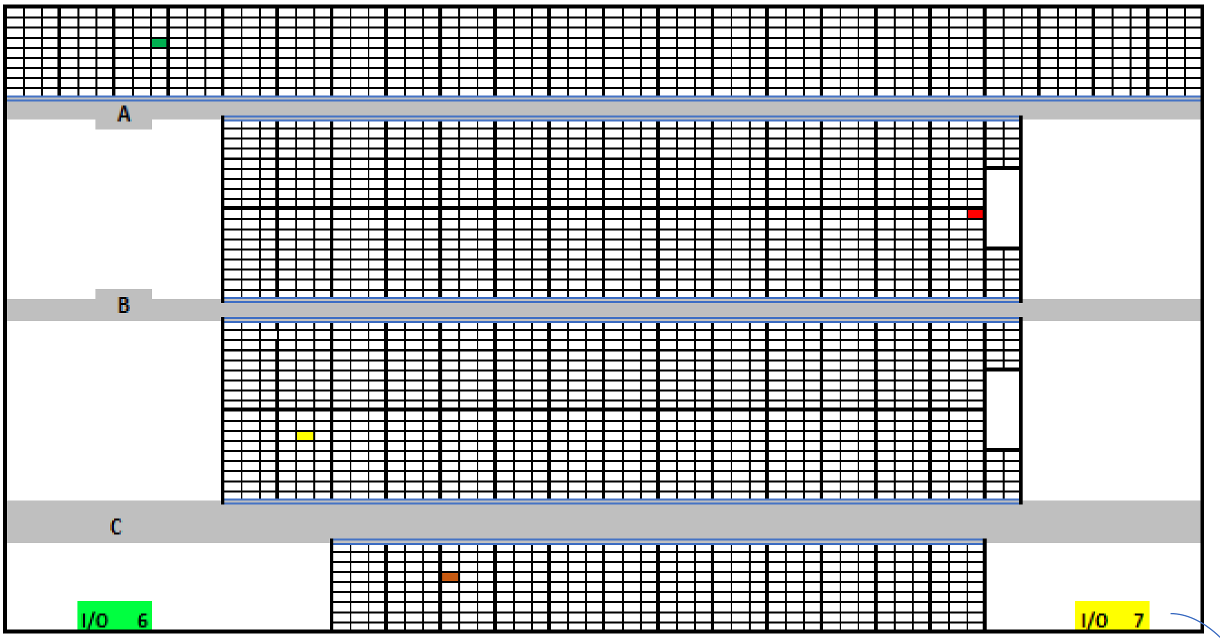

FIGURE 6-9, TEMPLATE HEATMAP PALLET AREA

To create a better understanding of the template that is used for the heatmap, a 3D model of the pallet area is created which can be seen in Figure 6-10. This model has the same characteristics as the 2D model. The I/O points are located at the same place and the colored locations are at the same positions. For example the green block is located at the ninth locations (from the left) and at the sixth layer (from below) in both figures.

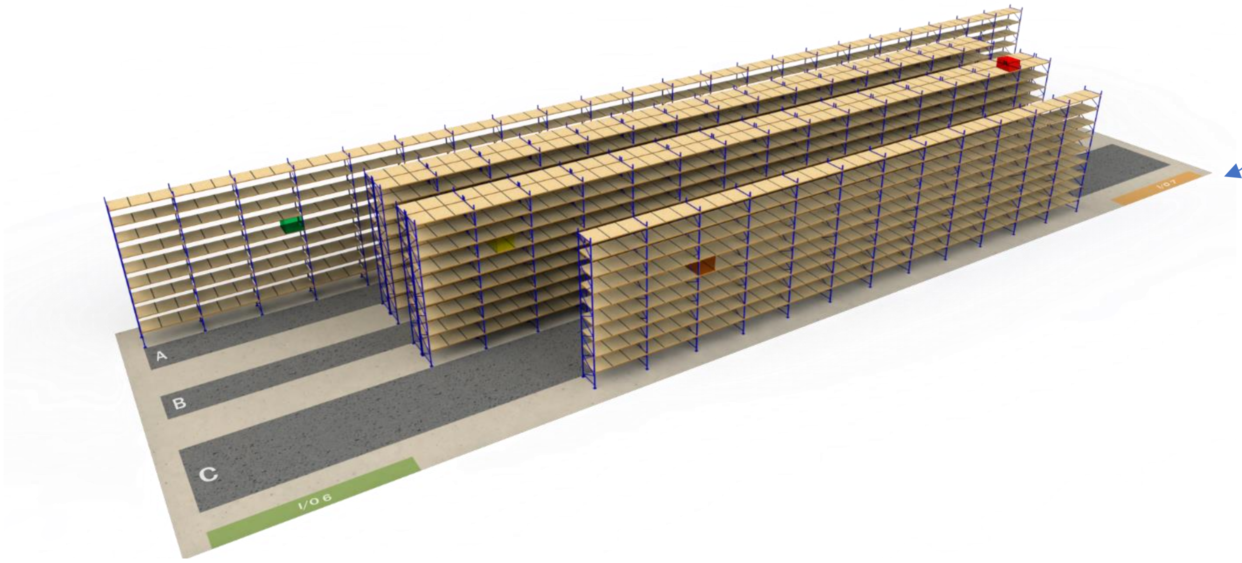

FIGURE 6-10, 3D MODEL PALLET AREA

6.4.1 I/O point spare parts

One I/O point is located at the spare parts department and responsible for the orders that come from customers or the external warehouse. In 2017 there were 3827 different parts that were sent from the spare parts department towards customers. These parts are divided over the pallet racks, shelves area and locations in production. In Table 6-3 the number of picks per part are displayed. From this table it can be concluded that 1585 parts are sold more than 10 times in 2017.

Pallet Racks		Shelves		Other	
Picks	**Amount**	**Picks**	**Amount**	**Picks**	**Amount**
500	46	500	97	500	0
400	57	400	108	400	0
300	72	300	135	300	0
200	86	200	166	200	0
100	141	100	265	100	3
50	203	50	443	50	4
20	322	20	766	20	14
10	407	10	1134	10	27
5	502	5	1594	5	44
1	699	1	2539	1	80
0	776	0	2963	0	88

TABLE 6-3, PICKS SPARE PARTS

6.4.1.1 I/O point 7, pallet area spare parts

Two heatmaps are created to show the number of picks per location. One for the shelving area and one for the pallet area. First the heatmap from the pallet area is discussed.

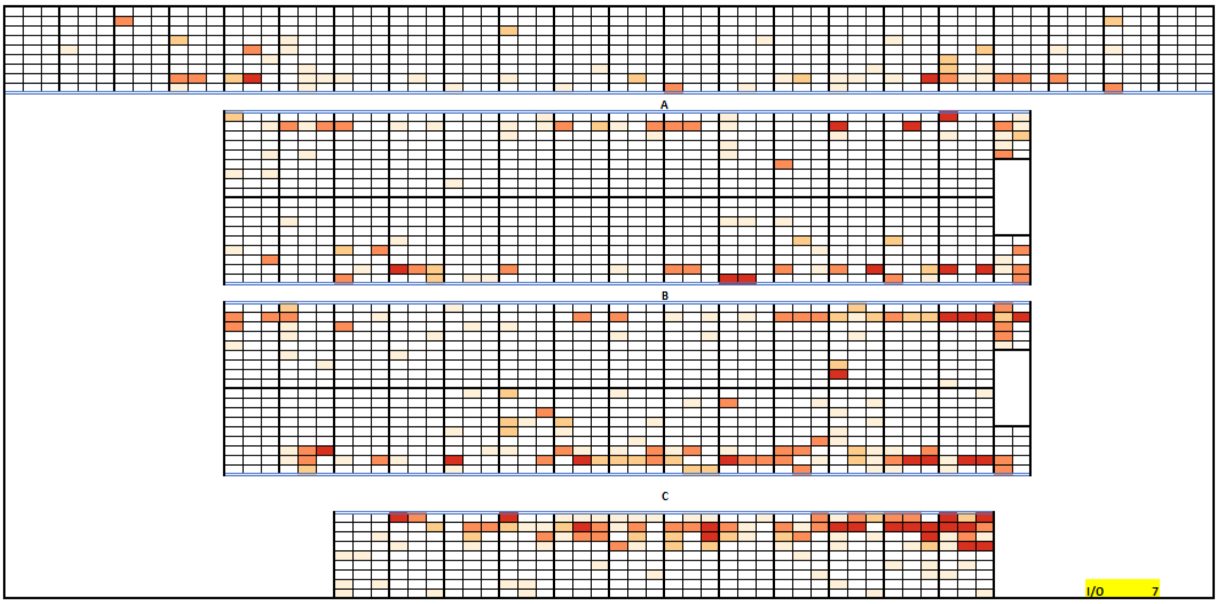

FIGURE 6-11, HEATMAP PALLET AREA, SPARE PARTS

The I/O point is located at the right bottom of the pallet rack area. There are three aisles in the pallet area and the racks are nine layers high. When analyzing the heatmap it can be concluded that the parts that are often picked are not all located close to the I/O point. There are a lot of parts located close to the I/O point, but there are also some parts that are picked often and are located far away from the I/O point. Some parts that are picked more than 500 times a year are located at the other side of the warehouse. In the warehouse the first three layers are accessible without a forklift. When analyzing the heatmap most of the parts are located at the first three layers, so that seems a good thing. But there is still room for improvement here.

<= 10	
> 10	
> 50	
> 100	
> 500	

TABLE 6-4, LEGEND

6.4.1.2 I/O point 7, shelving area spare parts

The second area is the shelving area. From this area more picks are performed. The parts that are picked here are relatively small. This area consists of three different floors. Almost all picks are done at the ground floor. However, there are some picks at the first floor but almost none at the second floor. A heatmap of the ground floor is depicted and analyzed in Figure 6-12. Picks can only be done at the double blue lines/positions.

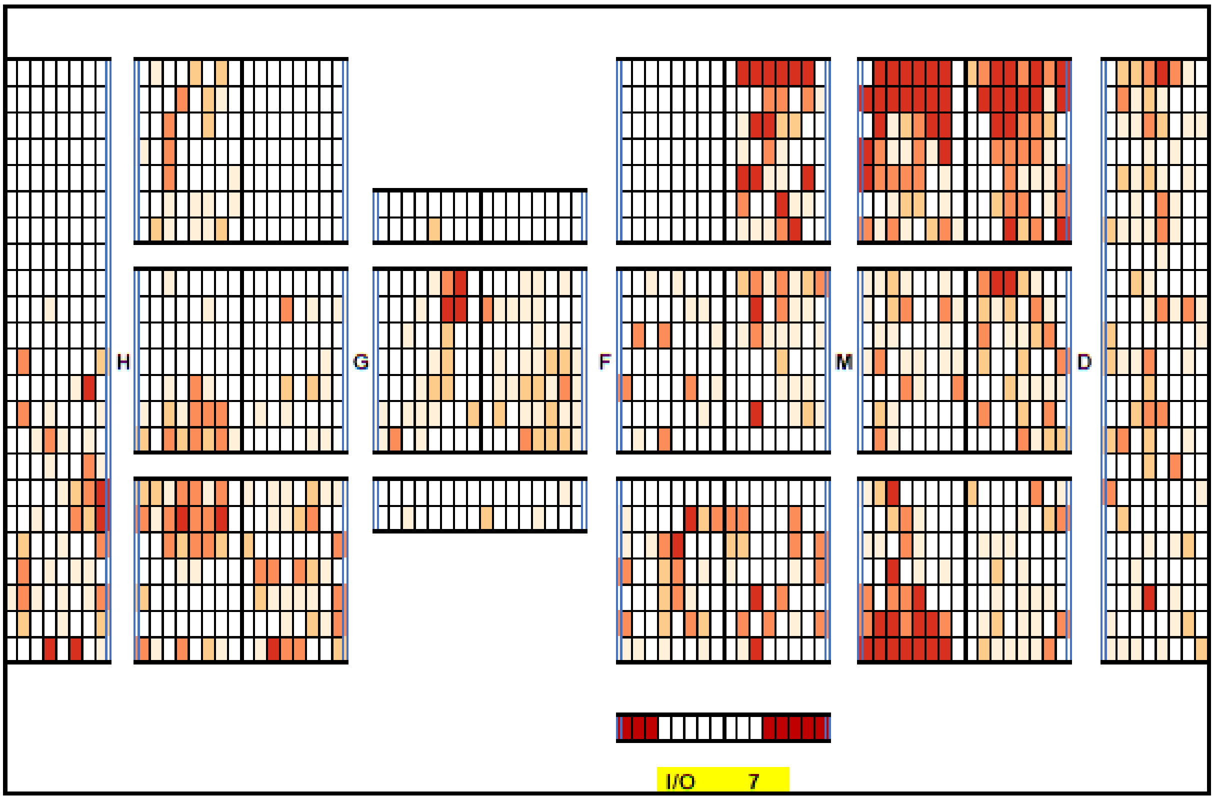

FIGURE 6-12, HEATMAP SHELVING AREA, SPARE PARTS

There are five aisles in the shelving area and two cross-aisles. Most of the shelves are eight layers high and picks are done from the double blue lines/positions. The I/O point is located at the bottom middle of the shelving area. When analyzing this heatmap some inefficiencies arise. There are a lot of parts that are picked more than 500 times which are located at the other side of the warehouse. The parts in the highest layers are picked less often which is a good thing, because a small ladder is needed to pick these parts which takes more time.

Some parts do not have a location within the logistic centre. These parts are located in production or outside the building. In total 88 parts are not located within the logistic centre. Of these 88 parts, 27 parts are picked more than 10 times a year. The picking of these is done by bike, where the operators cycle to the designated location to pick the part.

After analyzing the heatmap it can be said that the parts are not randomly stored and that some ideas are used to come up with this lay-out, but it seems that there is still room for improvement. By relocating the parts. the travel distance can be reduced and thereby opportunities for improving the picking process arise.

<= 10,	
> 10,	
> 50,	
> 100,	
> 500,	

TABLE 6-5, LEGEND

6.4.2 I/O point incoming goods

The other I/O point is located at the incoming goods department. From this location, production is resupplied. In 2017 there were 1738 different parts that were sent from the incoming goods department. These parts are divided over the pallet racks, shelving area and locations at production. In Table 6-6 the number of picks per part are displayed. From this table it can be concluded that 1428 parts are picked more than 10 times a year.

Pallet racks		Shelves		Other	
Picks	**Amount**	**Picks**	**Amount**	**Picks**	**Amount**
500	121	500	180	500	1
400	143	400	211	400	1
300	159	300	254	300	1
200	199	200	318	200	2
100	262	100	457	100	2
50	350	50	624	50	2
20	450	20	836	20	4
10	494	10	929	10	5
5	526	5	987	5	5
1	573	1	1096	1	6
0	594	0	1136	0	8

TABLE 6-6, PICKS INCOMING GOODS

6.4.2.1 I/O point 7, pallet area incoming goods

The picks of all the parts in the warehouse are plotted against the different locations. With this information two heatmaps are created. One heatmap for all the parts from the pallet area that are picked from incoming goods location and one heatmap from the shelving area that are picked from the incoming goods location.

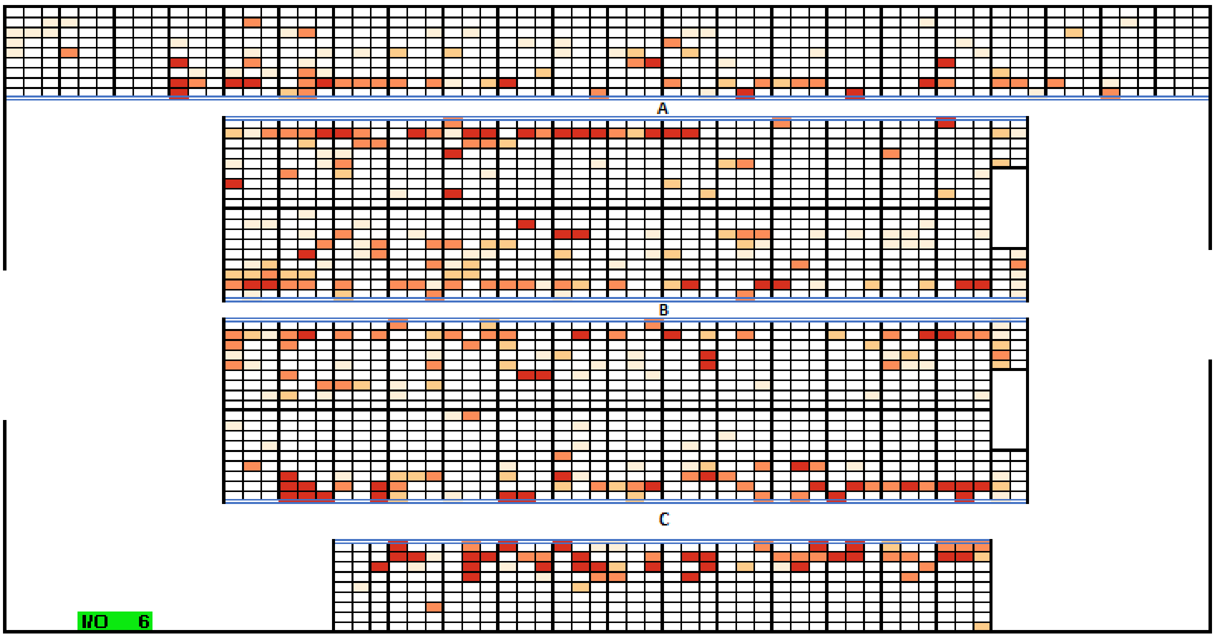

FIGURE 6-13, HEATMAP PALLET AREA, INCOMING GOODS

The I/O point is located at the left bottom corner of the pallet rack area. There are three aisles in the pallet area and the racks are again nine layers high. As shown in the heatmap there are pallets located throughout the entire warehouse. Some parts that are picked more than 500 times a year are located at the other side of the warehouse. Within the warehouse, the first three layers are accessible without a forklift or reach truck. When analyzing the heatmap there are some parts located at higher layers, which can cost extra picking time. Overall there are some improvement possibilities here.

<= 10,	
> 10,	
> 50,	
> 100,	
> 500,	

TABLE 6-7, LEGEND

6.4.2.2 I/O point 6, shelving area incoming goods

The second area is the shelving area. From this area the small parts are picked. In Figure 6-14 a heatmap of the ground floor is depicted. Most picks are done from this ground floor area.

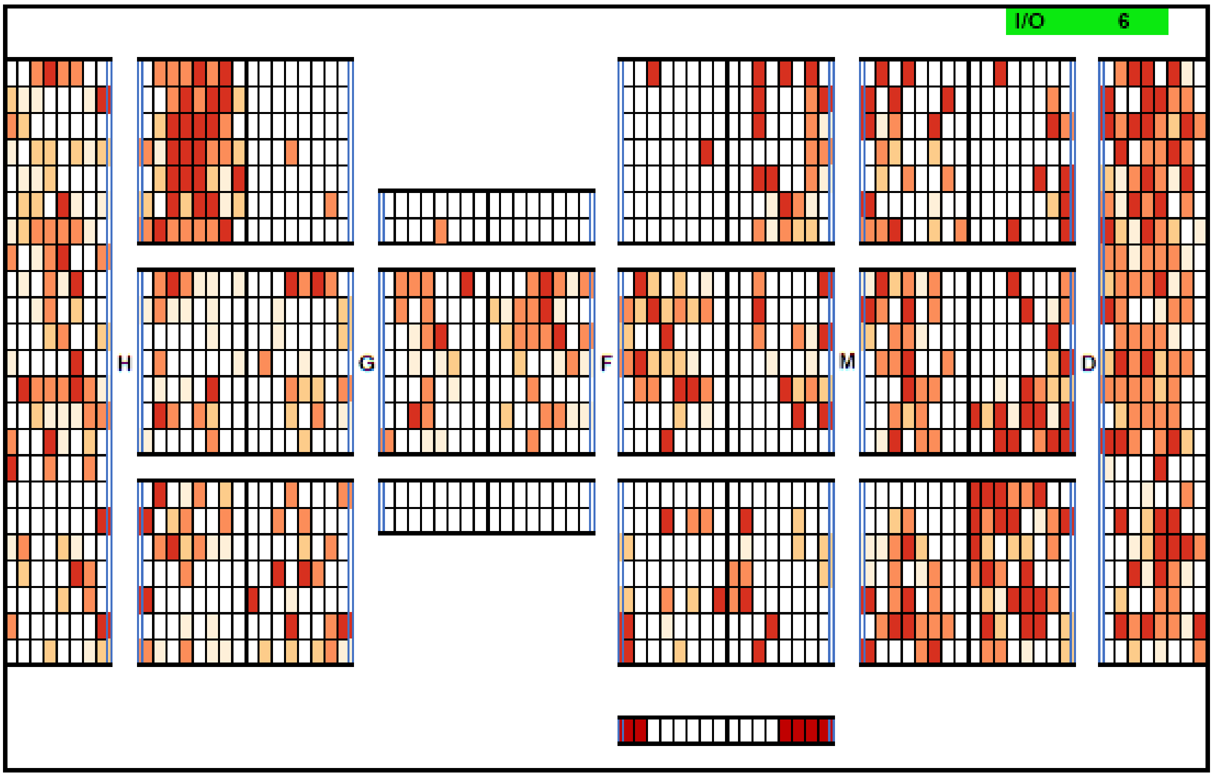

FIGURE 6-14, HEATMAP SHELVING AREA, INCOMING GOODS

There are five aisles and two cross-aisles in this shelving area. Most of the shelves are eight layers high and picks are done from the double blue lines/positions. The I/O point is located at the incoming goods department, the green block in Figure 6-14. When analyzing the heatmap there are some improvements possible. There are parts located far away from the I/O point that are picked quite often. There are also some parts located at the higher layers which are only accessible with a small ladder.

After analyzing the heatmaps it can be concluded that not all the parts are located correctly. There are parts located far away from the I/O point or not at the right height. Relocating these parts can result in a reduction of travel distance and travel time, which can result in a more efficient picking process.

<= 10,	
> 10,	
> 50,	
> 100,	
> 500,	

TABLE 6-8, LEGEND

6.5 Order picking

Within this section, the possible bottleneck of having an order picking strategy that is not optimal in the current situation, is analyzed. As mentioned before the order picking process can start at two I/O points, dependent on the kind of order. First these two different I/O points are discussed. Thereafter the order picking policy is discussed.

Spare parts:

For the spare parts department 66 different orders are clocked, which are added in Appendix D. On average the number of order lines is five. The average time to pick an order is 17 minutes, which means that approximately 205 seconds per order line are needed. The average weight of the orders is 25 kg.

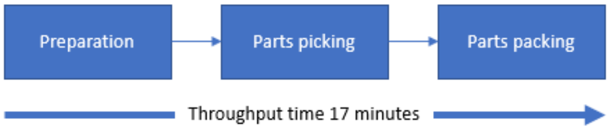

FIGURE 6-15, SPARE PARTS PICKING PROCESS

Incoming goods:

For the incoming goods department 24 different orders are clocked, which are addressed in Appendix E. On average the number of orders lines is 42. The average picking time is 18 minutes, resulting in approximately 26 seconds per order line.

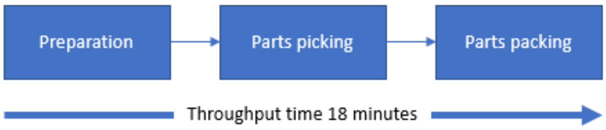

FIGURE 6-16, INCOMING GOODS PICKING PROCESS

When analyzing the two I/O points the throughput on average is almost the same, but because of the higher amount of order lines in the incoming goods department the average picking time per order line is significantly lower than for the spare parts. Where the average picking time per order line is 205 seconds at spare parts, the average picking time at incoming goods is 26 seconds.

There are three activities present in the order picking process: preparation, part picking and part packing. These three activities are discussed in the following sections.

Preparation:

The preparation phase starts when a new order comes in. This can be an order from production that is handled by incoming goods or an order from an external customer that is handled by spare parts. The documents are printed in the office and put in a tray. The operator picks the documents and start with the picking process.

This process is as efficient as possible at this moment. With the new ERP system this can be automated, but until it is automated there is no improvement potential.

Parts picking:

After the documents are picked, the part picking phase can start. The operator takes a cart and starts picking the different parts. During this picking process there are a couple of possible inefficiencies. Inefficiencies according to the location of parts are not mentioned in this section, because this is already discussed in the section about the storage policy. The equipment used and the location of the packing process are discussed underneath.

Equipment:

The first inefficiency is the equipment that the operators use at Trioliet. They can use a forklift or reach truck, but these are only used when a part is needed that is not accessible by hand. For the order picking they are using a cart depicted in Figure 6-17 or perform the pick by hand. When parts are needed from production they use a bike.

Disadvantage of the cart is that double handling is needed. First the parts have to be put on the cart and thereafter put into the pallet. Besides that, not all the parts of an order can be put on the cart at once. Another disadvantage is traveling speed. The last disadvantage is that only the first three pallet layers are accessible when using the cart or performing picks by hand.

FIGURE 6-17, CART TRIOLIET

Locations:

The picking process start at one of the packing tables. These tables are located at location 6 and 7, Figure 6-18. When the order can be packed in a box, the parts are moved from the warehouse to the packing table. When a pallet is needed to store all the parts this can be done at the picking table or at the orange locations, Figure 6-18.

Originally the green locations were created for temporary storage of pallets during the picking process, but currently these locations are occupied with parts from the warehouse.

Inefficiencies in the picking process regarding the locations is that the packing tables are relative far from the temporary storage locations, with as a consequence long travel times. Moreover the ground space is mostly occupied which creates significant inefficiencies.

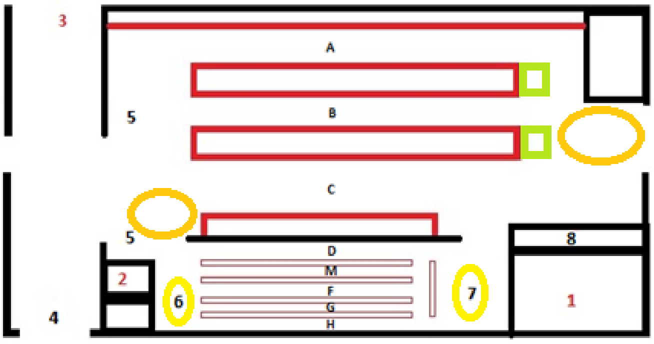

FIGURE 6-18, MAP LOGISTIC CENTER

Parts packing:

After all the parts of an order are picked, the process is not finished. The parts of an order have to be packed. At Trioliet packing the order is a long and costly process, because there are a lot of heavy and difficult parts and the packing process is completely manual. Many parts, especially in the pallet area, cannot be sent in a box, ziplock bag or even on a pallet. That makes the packing process a time-consuming and expensive process. The packing process is especially a problem within the spare part department, because the products that are sent from the incoming goods department do not need to be wrapped up. These parts are sent in boxes to the production department or as full pallet loads to suppliers.

In Table 6-9 the total costs of packing material are displayed. The total costs of all the packing material, excluding pallets, is more than € 30,000 a year. More than € 10,000 a year is spent on just the tape with Trioliet text on it. The table shows that the total use and cost of packing materials is significantly high.

Product	price	Amount	Total
Void fill 500L	19	94	€ 1.786,00
Plastic bubble wrap	28,5	194	€ 5.529,00
Ziplock bag 80x12	0,010	24000	€ 248,40
Ziplock bag 120x180	0,015	18000	€ 278,10
Ziplock bag 150x200	0,028	3000	€ 82,50
Ziplock bag 160x230	0,030	6000	€ 179,94
Ziplock bag 150x320	0,029	1500	€ 43,80
Ziplock bag 190x250	0,031	15000	€ 471,75
Ziplock bag 230x320	0,049	7000	€ 339,15
Plastic bag	2,58	60	€ 154,80
Box 300x300x300	1,02	2000	€ 2.040,00
Box 305x220x120	0,28	3000	€ 840,00
Box 305x220x8	0,35	3000	€ 1.050,00
Box 400x400x350	2,2	220	€ 484,00
Box 420x420x420	2,1	500	€ 1.050,00
Box 450x150x140	0,52	3800	€ 1.976,00
Box 550x250x250	1,89	1000	€ 1.890,00
Box 600x200x200	0,9	500	€ 450,00
Box 750x300x300	1,27	500	€ 635,00
Box 180x120x120	0,19	3000	€ 570,00
Tape with print	1,97	5086	€ 10.019,42

TABLE 6-9, PACKING MATERIALS

The average time to pack an order is almost as long as picking the order. So the packing process is also a time-consuming process. Problems during the packing process are that the packing process is performed manually what cost a lot of labor time and that the products from Trioliet are often heavy, sharp and difficult to handle.

So it can be concluded that the order packing process is an important part of the whole order picking process and that the process should not be neglected.

There are a couple of possible causes for problems during the picking process:

- Single order picking, because orders must be picked in real time to meet shipping schedule.
- Often even part picking in pallet area, because of heavy and difficult to handle parts.
- Equipment used makes the picking process a more time-consuming process.
- Packing of orders is time-consuming and costly.

6.5.1. Example

To create a better idea of the picking process, two examples are created and explained. Both examples are orders from the spare parts department. The first example is a small order that has to be sent upon the same day. The other example is a bigger order which does not need to be sent upon the same day.

Example 1: The first order is a small order with just four different components and a total of 18 parts. It takes around seven minutes to pick and pack this order. The parts of this order are located relatively close to each other. 84926 and 05261 are located at the fast pick lane and 11741 and 23116 are located in aisles close to the picking point. The parts in this order are close to each other and the picking location. In this example, the packing of the parts requires the most time.

Product Nr.	Location	Amount
11741	0A4500	1
23116	0C361A	1
84926	0F4903	15
05261	0F5201	1

TABLE 6-10, EXAMPLE ORDER 1

Example 2: It takes around 60 minutes to pick the whole order of this example. This order consists of 17 different products, but two of these products are sets (05442 and 05847). These sets consists out of a product and another set. The sets within this set are normally prepacked, but the 05442 is not prepacked. The operator first has to print the bill of materials of the set and can then pack the two parts of that set. Furthermore, it takes an enormous amount of travel time to pick all the parts. Another problem is that a lot of the parts in the pallet area are heavy and difficult to handle, which makes multiple picks at once almost impossible. Altogether it takes a significant amount of time to pick this order.

Product Nr.	Location	Amount
24907	0A401A	1
05851	0A402A	1
2003353	0A450A	1
15284	0B321A	3
84002	0C192A	5
51341	0C250B	1
11954	0D4507	5
05002	0E0705	4
S742034	0E3803	15
98168	0F2404	1
52605	0H4006	2
21561	0H4102	2
27228	0H4103	12
21561	0H4602	5
50633	2G4602	3
05442	-	3
26848	*0B381A*	-
1003	*0F3003*	-
05847	-	2
200393	*0C374A*	-
0500447	*0F4902*	-

TABLE 6-11, EXAMPLE ORDER 2

6.6 Storage system small parts

The possible bottleneck that the storage system for small parts is currently not optimal is discussed in this section. At Trioliet they believe that another storage system will improve the process and less ground space is needed. In this section the storage system and the problems of this system are discussed.

Currently, all the small parts are located in the shelving area. They use different sizes of bins to store all the parts. One shelf contains eight layers with overstock on top. An example of such a shelf is depicted at Figure 6-19. One shelf can contain around 24 bins on average.

Ground area of 23,435x10,050 centimeter is used to store all the small parts. At the ground floor 198 shelves are located. In Figure 6-20 the lay-out of the ground floor is depicted. The lay-out of the first and second floor is comparable with the lay-out of the ground floor.

FIGURE 6-19, PICTURE OF A SHELF

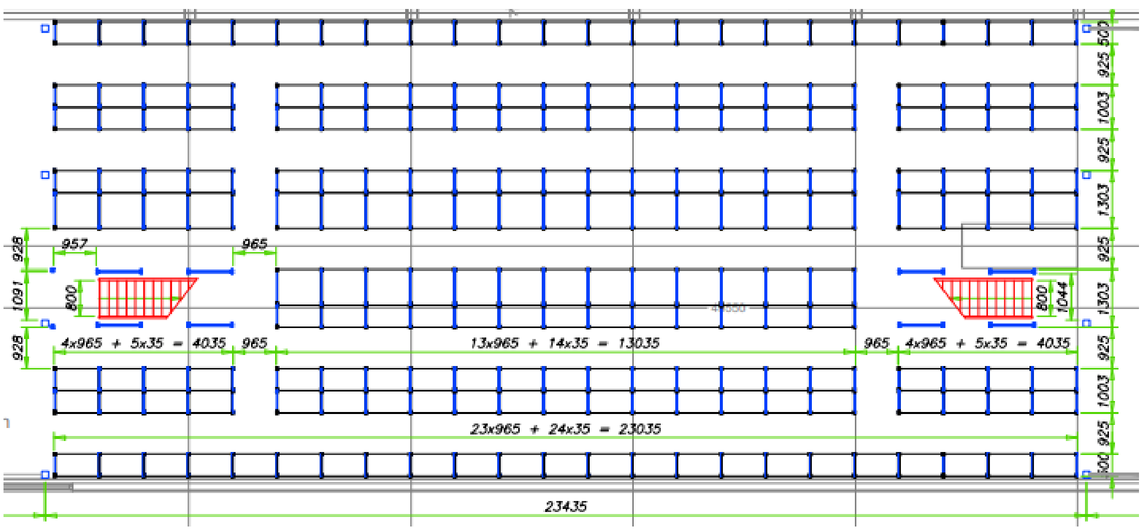

FIGURE 6-20, MAP GROUND FLOOR SHELVING AREA

In total 9625 parts are located among these three floors. On the ground floor 4974 parts are located. Whereas 2616 parts are located on the first floor and 2035 parts are located on the second floor.

Major disadvantages of this storage system is that a lot of ground space is needed, travel time is high and a lot of lifting needs to be performed by the operators. These are addressed shortly;

- A lot of ground space is needed to locate all the parts, a total of 236 square ground meters is used to locate all the parts.
- Currently the parts are located throughout the entire shelving area which creates a lot of travel time. Some parts are located on the first or second floor which causes even more travel time.
- Parts can be located on the lowest or highest layer which is logically not an ergonomic working height and can cost extra picking time, because a small ladder is needed to perform the pick.

6.7 Conclusion

The possibilities for bottlenecks in the current situation at the logistic center of Trioliet are validated in this chapter. The bottlenecks are exposed regarding observations, ERP data and interviews. The bottlenecks are summarized in this section:

Receiving process:

- Unnecessary search time, because documents are taken of the pallet. The second operator has to pick the documents and furthermore needs to search for the box or pallet.
- Not enough temporary storage space. Boxes and pallets are located wherever there is space, creating chaos in the receiving area.

Set production:

- Long travel distances, because the parts within a set are located throughout the entire warehouse.
- All the different components must be packed in separate bags which requires a lot of time.
- Each ziplock bag needs a handwritten product number which requires a lot of time.
- There is no bulk production because of insufficient stock.

Storage of parts

- Parts are located throughout the entire warehouse, with as consequence long travel distances.
- Parts are located at high locations with as consequence long picking times.
- Two packing locations, resulting in difficulties for an optimal lay-out.

Order picking

- Single order picking, because orders must be picked in real time to meet shipping schedule.
- Often even part picking in pallet area, because of heavy and difficult to handle parts.
- Equipment used makes the picking process time-consuming.
- Packing of orders is time-consuming.

Storage of small parts

- A lot of ground space is needed to locate all the parts.
- Long travel distance to pick all the parts.
- No ergonomic working height.

In the following chapters these five bottlenecks are discussed further and possible improvements upon efficiency regarding these bottlenecks are discussed and analyzed.

Chapter 7 - Solution design

In the previous chapter the processes and possible bottlenecks are analyzed and explained. With this information the fourth research question is answered: "What is a suitable picking policy and how should the parts be stored to create an efficient flow of goods". The conclusion from Chapter 6 is that there are a couple of processes within the logistic centre that are not efficient at this moment. This chapter starts with the processes in the receiving area within Section 7.1. In Section 7.2 the assembling of sets is discussed. Besides that, Section 7.3 concerns the travel time within the warehouse. Within Section 7.4 the inefficiencies of the picking process are discussed. Lastly, Section 7.5 describes a goods-to-person picking method.

7.1 Receiving process

There are two inefficiencies present within the receiving process:

- Unnecessary search time because the documents are retrieved from the pallet and the pallet is located somewhere. The second operator has to pick the documents and search for the box or pallet.
- Not enough temporary storage space. Boxes and pallets are located wherever there is space left and thus creating a mess in the receiving area.

When analyzing the first problem a simple solution is to write the temporary storage location upon the document. When writing the location on the document the searching time can be reduced and the process can be improved, however because of the second problem this will not work. There is not enough storage space at the receiving area. Parts are located where there is space left and therefore that increases the searching time.

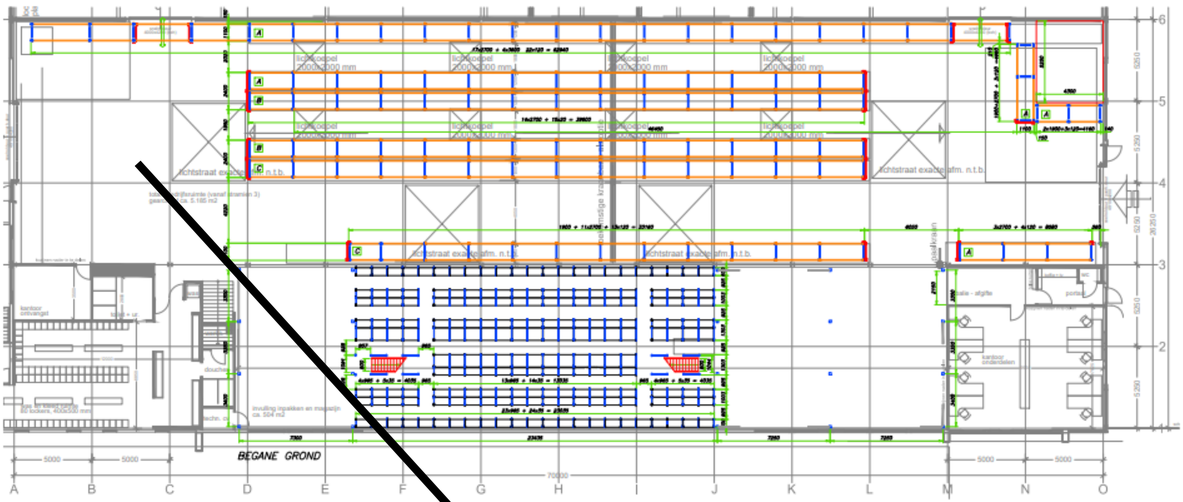

FIGURE 7-1, LAY-OUT WAREHOUSE

A solution for this problem would be a temporary storage pallet rack for the incoming goods (Y) and a temporary storage pallet rack for the goods needed in production (X). This will increase the storage space (Z) and makes the receiving area a well-organized and better looking area.

With this solution the parts can be located and can easily be found after the documents are taken from the pallet.

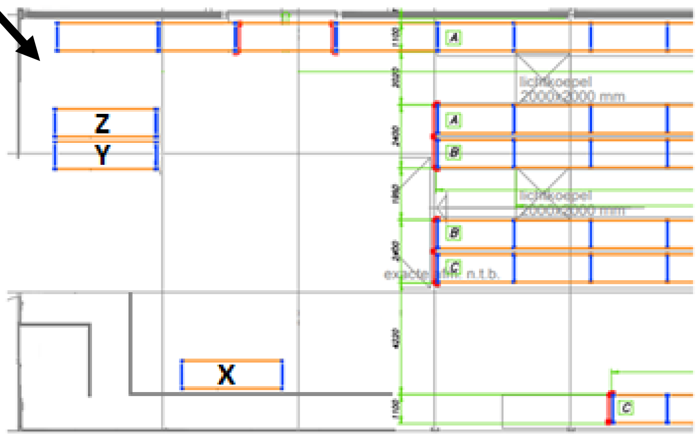

FIGURE 7-2, LAY-OUT ZOOMED IN

7.2 Set production

The production of the sets within Trioliet turned out to be an inefficient process based on the conducted root cause analysis. There are four causes for this:

- Long travel times, because the parts within a set are located throughout the entire warehouse.
- All the different components must be packed in separate bags, which takes a lot of time.
- Each ziplock bag needs a handwritten product number, which requires a lot of time.
- There is no bulk production, because stock is insufficient.

These four causes are analyzed in three different sections. In the first section the location of the parts is analyzed. The second section deals with the packing of the parts and the writing of the product number. These two manually operated activities occur frequently and require a lot of time to perform. The last section discusses the Trioform knife set.

In Section 7.2.3 the Trioknife set is discussed separately. This set consists out of two bolts, rings, nuts and a sort of Trioknife. There are four different Trioknifes, but the bolts, rings and nuts are the same for these sets. The sets with a Trioknife cover in total 85% of the total amount of sets picked, because of that these sets are discussed separately. All the other sets are discussed together in the other sections.

In total there are 73 sets which are picked more than ten times a year at Trioliet. In all these sets together 244 different parts are needed and the total number of sets is 4937. Currently the average time to pick a set is 3.5 minutes, which results in a total picking time of almost 288 hours a year.

Averages	
Orders per set	68
Order lines per set	5.5
Parts per order line	2.86

TABLE 7-1, AVERAGE OF SETS

7.2.1 Travel time

The travel time is the time needed to pick all parts of a set. The travel time is currently relatively high because the parts needed in a set are located throughout the entire warehouse. The travel time to pick a set can be reduced by locating the parts that are needed together in a set close to each other. As mentioned in the literature, this can be done by the OOS slotting method. OOS aims to store parts, that appear together in orders, close to each other (Mantel, Schuur, & Heragu, 2007). This will probably result in a shorter travel distance. How important this slotting of sets is to improve the efficiency is dependent on the number of sets produced at once. When a set is produced once every week the travel time is an important aspect. However when for example twice a year 25 sets are produced, the travel distance is just a small part of the total time needed to produce the sets. Regardless of the importance, the travel distance is something that needs attention. The location of the sets is analyzed first and an improved lay-out is created.

For all the sets a total of 244 different parts is needed. In the pallet area a total of 32 parts are located and all the other parts are located in shelving area. The average travel distance is 65 meters. A heatmap with all the locations is displayed in Appendix F. When analyzing this heatmap it is visible that the parts within a set are located everywhere and because of this the travel distance for a set is unnecessary high. Eight parts are located at the first floor and one part is located at the second floor. Besides that, there are also parts located at the other side of the pallet racks, costing a significant amount of travel time. After analyzing the heatmap it can be concluded that the travel distance can be reduced drastically by introducing a new lay-out. In the upcoming sections, first the shelving area is discussed, followed by the pallet area.

7.2.1.1 Shelving area

A set contains on average 5 parts that are located in the shelving area. A set is created by picking all the underlying components and pack them together. The picking process of the sets can be seen as multi item order picking. A set always consists out of the same parts, but there are parts that are needed in multiple sets. So according to the literature the order oriented slotting strategy could be used to minimize the set picking process. The implementation of the OOS strategy is explained in this section.

The decisions has been made to use a complete shelf row for all the parts needed in the different sets. In total, nine shelves are used to locate all the parts. This means that allocation of parts to a location can be done from scratch. First of all, all the sets and the parts needed in these sets are listed. To allocate all the parts, a heuristic with as starting point the OOS strategy is created and is explained below:

A heuristic is created to allocate the parts to their new location. The heuristic allocates parts to a specific shelf, such that the travel distance between parts within a set is minimized. The following indices, parameters and variables are used:

The heuristic is explained in more detail in appendix G.

i	= number of SKUs	= 1,2,.....,I
p	= location	= 1,2,.....,P
k	= order set	= 1,2,.....,K
O_k	= all SKU in order k	
$mult(k)$	= multiplicity of order k	
dp_1p_2	= distance from location p_1 to location p_2	
x_{ip}	= if SKU i is located at p	= {0,1}
Zkp_1p_2	= if order k is located at location p_1 and p_2	= {0,1}
S	= amount of SKU locations in a shelf	= 24

The following minimization formula is used to find this new allocation:

$$Min\ \sum_{k=1}^{k} mult(k) * \sum_{p_1}^{p} \sum_{p_2}^{p} dp_1p_2 * Zkp_1p_2 + \sum_{k=1}^{k} mult(k) * \sum_{i=1}^{I} \sum_{p=1}^{P} d_{op} * x_{ip}$$

$$\sum_{p=1}^{p} x_{ip} = 1 \qquad \forall\ i$$

$$\sum_{i=1}^{I} x_{ip} \leq S \qquad \forall\ p$$

$$x_{i1p2} + x_{i2p2} - 1 \leq Zkp_1p_2` \qquad \forall\ p_1p_2 \quad \forall\ k \quad \forall\ i_1i_2 \leftarrow O_k$$

$$x_{ip\ ,Zkp_1p_2} \qquad \{0,1\} \qquad \forall\ i,p,k,p_1p_2$$

The following input is used:

- The total number of SKUs is 201 — i = 201
- The total number of locations is 9 — p = 9
- The total number of different sets is 73 — k = 73
- Mutual distance between shelves is equal — p_a to p_b = 1
- On average there is space for 24 parts on a shelf — S = 24

    - An example of some sets is depicted in Appendix H.
    - A picture of the shelves used is depicted in Figure 7-3.

FIGURE 7-3, SHELVES

To find a solution for this heuristic, software from AIMMS is used. AIMMS is a prescriptive analytics software: "AIMMS, as a complete optimization modeling system, comes with al functionality to develop and create complete optimization applications. This means that a large set of mathematical model types can be formulated within AIMMS" (AIMMS, 2018).

The heuristic is implemented in the program of AIMMS to find allocations with minimum total travel distance. The results of this heuristic are depicted in Table 7-2, whereby each shelf can contain 24 bins.

	Shelf 1	Shelf 2	Shelf 3	Shelf 4	Shelf 5	Shelf 6	Shelf 7	Shelf 8	Shelf 9
Part 1	52053	78257	51768	51828	85006	51782	78011	78061	51750
Part 2	30992	22684	95463	86116	78002	52031	78001	51708	51801
Part 3	51826	39393	84730	78115	84801	83934	25048	24153	25624
Part 4	51839	86206	9800763	15882	51733	78021	51734	51731	88172
Part 5	78211	78209	30991	25657	51848	78104	78121	51852	51853
Part 6	70261	2003273	84477	78005	51891	78069	78098	6000760	52120
Part 7	53514	47070	50644	25638	31967	83915	2007628	2022581	84523
Part 8	52056	78338	78039	51829	78051	52017	52024	51902	51855
Part 9	31392	31010	95735	81626	78032	52025	52037	52036	78036
Part 10	51726	78167	70363	51832	26167	44130	80816	84808	
Part 11	51913	X50202	98338	84825	88173	30870	33564	65118	
Part 12	78210	51758	65029	44127	51893	52046	78012	51850	
Part 13	78221	2005430	86510	51710	2023187	44129	9400985	9400342	
Part 14	80655	6000278	50147	83937	86216	95140	30250	84119	
Part 15	52057	70179	78040	78020	51856	78116	51857	78118	
Part 16	65064	83610	31437	85116	52019	78114	52060	5010266	
Part 17	39327	70184	78285	51844	86812	27228	52076	52074	
Part 18	78214	X50481	51732	26184	52072	52097	52098	78163	
Part 19	78207	51759	86937	80616	6000761	51874	51875	52090	
Part 20	39230	86225	52047	52015	9400947	9400967	9400965	81045	
Part 21	85106	6000279	15881	84822	51711	51716	78003	85008	
Part 22	52058	78171	78062	78022	96409	9400310	5010415	51807	
Part 23	85238	53312	70103	85141	70341	78294	78292	78112	
Part 24	46766	34374	25636	51845	78270	27931	51701	9400956	

TABLE 7-2, PARTS CONNECT WITH SHELVES

With this heuristic the parts can be located in a shelf. In Table 7-2 parts are connected to a shelf. On which layer the part is located depends upon the size of the bin. Small bins are located at higher layers and larger bins are located at lower layers. In Figure 7-4 a schematic view of three shelves is depicted. With the computed heuristic, parts are located in a shelf. The location within this shelf is dependent on the bin size and is done manually.

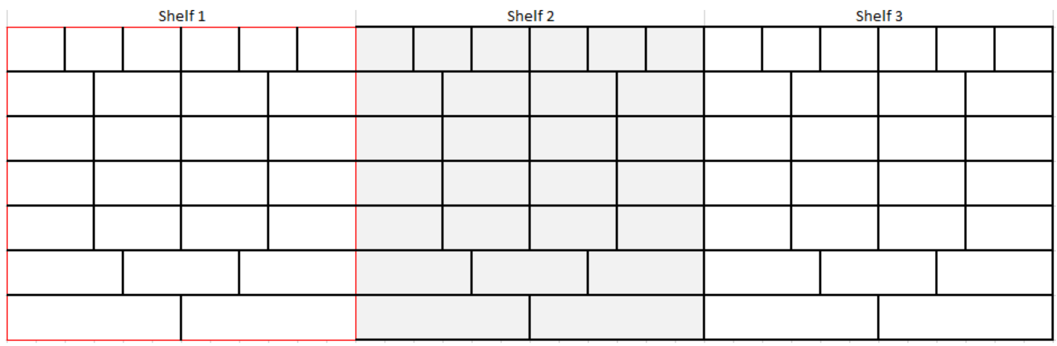

FIGURE 7-4, REDESIGN SETS SHELVING AREA

With this redesign the total travel distance can be reduced significantly.

7.2.1.2 Pallet area

A set contains on average 0.5 part from the pallet area. Often the parts from the shelving area are picked together in an ziplock bag and combined with the parts from the pallet area in a box. Most sets contain zero or one part from the pallet area. For these parts OOS slotting has no benefit. In total there are 22 different parts that are needed in a set together. For those parts OOS could be beneficial.

For the shelving area the decision has been made to use a complete new allocation from scratch, but for the pallet area a couple of location changes are enough. The 22 parts are needed in one or at the most two different sets. Combining these sets results in the combinations displayed in Table 7-3.

By analyzing this table and using the OOS literature there are a couple of location changes needed to reduce the total travel time. The parts that are needed together have the same color.

The parts with the same color need to be located together according to the OOS strategy. Those parts are needed together in a set or a combination of two sets with partly the same parts. Some of the parts are already located close to each other: 2003830, 12413 and 12414 are located next to each other and are also needed in the same sets. 29298 and 29299 are located far away from each other, and this results in long travel times while these are needed together in a set.

So there are a couple of changes possible to reduce the total travel distance for the different sets. The parts are not allocated yet because this can better be done while adjusting the entire warehouse. When adjusting the entire warehouse these 'set-parts' are located as close together as possible to eventually minimize the total travel distance.

Article Nr.	Location
29298	0A22XC
29299	0C22XB
84072	0C202C
43204	0C292C
44187	0C33XC
2009392	0C34XB
2003830	0C360B
12413	0C360C
12414	0C360A
2001797	0C32XB
2003828	0C340B
12414	0C360A
2001791	0C372A
25736	0C371A
26854	0C370A
30225	0A221B
30228	0A181C
2009389	0C34XA
44127	0B270B
2009390	0C342C
96696	0B130A
9400955	0C181C

TABLE 7-3, LOCATION SETS PALLET AREA

7.2.2 Manually set production

Two time-consuming processes within the set production are the packing of parts and the writing of the product number. Both are manual process. As shown in Section 6.3 the picking and packing of sets can take up to 16 minutes for one set. There are a couple of possible options to make this process more efficient. The first option that is discussed is outsourcing. The second option is order prepacked sets and the last option is (semi-) automatization. These options are outlined in the following sections.

7.2.2.1 Outsourcing

Outsourcing is a business practice in which a company hires another company or individual to perform tasks, handle operations or provide services that are either usually executed or had previously been done by the companies own employees (Rouse, 2018). Outsourcing can result in lower costs, improve efficiencies and gain speed. In this case the first reason to outsource the production of sets is to lower the total cost. Outsourcing can be done at an external location or at the firm itself, both of these options are discussed. The third party provider in this case is Larcom. Larcom is a company with a social purpose and whom already has a partnership with Trioliet. Larcom offers suitable work to people who are dependent on adapted work for a short or longer period of time. Because of the social approach of Larcom the employees are relative affordable and simple tasks can be done for an affordable price. The production of the sets can be done at Larcom or an employee can come to Trioliet, both options are discussed in the next paragraphs.

The first option is hiring an employee from Larcom that comes to Trioliet and produces the sets the same way the employees of Trioliet are doing it currently. An employee of Larcom can be hired for a pre-arranged number of hours/days and costs between €9.75 and €10.50 per hour depending on the difficulty of the task. In principle the same employee can come every day, so he or she can learn the task and be able to fulfil it according to Trioliet's desires.

The other option is to bring all the parts to Larcom and let them produce the sets at their location. This saves a working place, but costs extra time to bring the parts and pick the sets. The price of outsourcing the set production is dependent on the set size. For example a set with a total of 6 parts in a ziplock bag is €0.09. When this option is chosen, a combination price has to be determined.

7.2.2.2 Purchase Pre-packed

Almost all the underlying components are purchased from suppliers. Many of the parts needed in the same set are purchased from the same supplier, which is a major benefit. When the parts that are needed together can be pre-packed by the suppliers in the right amounts, this can save a lot of time at Trioliet. This option is only interesting when the parts can be packed in the right amounts and when a lot of parts for a set are ordered by the same supplier.

An example where the purchase of pre-packed sets can be efficient and cost effective is the set for a Trioform knife. This set consists out of three different parts and a total of six parts. The costs of these parts alone is €1.21. When buying this set as a prepacked set the costs are €1.26. In this case the extra cost would be €0.05 per set.

This option has to be researched per set, but can be cost-effective for some of the sets present at Trioliet.

7.2.2.3 (Semi-) Automation

As mentioned before the picking and packing process is fully manual. Automatization can help in making the process more efficient and cost effective. At Trioliet there are a lot of different sets with different parts. These parts have different sizes, weights and dimensions. Therefore, automatization is difficult to integrate at Trioliet. After discussions with different automatization suppliers it can be said that full automatization is not realistic at the moment. However, there are multiple option to automate parts of the process. Some of these are discussed here.

A simple automatization option that will help Trioliet to make the set production faster and also provides the sets with a more professional look is a label printer. As explained earlier, the operator writes the product number on the ziplock bag. When introducing the label printer they can print all the labels and just put the label on the ziplock bag, saving lots of time. An example of such a printer is the Citizen label printer depicted in Figure 7-5. This printer can print up to 15 centimeter per second. The costs of 100,000 labels is just €250.- and the purchase cost of the printer is €290.- This is just an example of a possible label printer, but there are several options applicable for Trioliet.

FIGURE 7-5, LABEL PRINTER (BYPOS, 2018)

A more complex automatization option is a packing machine. A packing machine automates the whole packing process and can automate the labeling process as well. There are a lot of packing machines with different options. The process can be fully automatic or just some steps within the process can be automated. After consultation with suppliers of packing machines it can be said that a semi-automatic packing machine would be the most suitable option for Trioliet. The sets within Trioliet are needed in relative small amounts and the components have different sizes, weights and characteristics. When a fully automatic packing machine is used, the changeover times are too long compared to the benefits. The most important benefit of a semi-automatic packing machine is a faster packing time, but there are some additional benefits:

- Professional appearance through printed labels.
- Clear printed barcode and product number.
- Cost reduction, the bags that are used are cheaper.

A packing machine that is advised is the VVS APE0410 from Altrimex. The input of parts is manual. All the parts are put into the catch box and through a hand or foot switch the bags are filled and sealed. With a thermal transfer printer, the barcode and product number can be printed on the bag. The total costs of this machine is approximately €50,000.- .

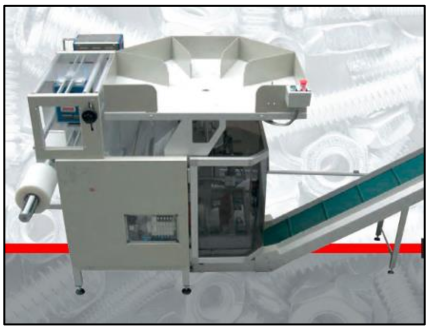

FIGURE 7-6, PACKING MACHINE (ALTRIMEX, 2018)

Another possible packing machine is the “Speedpack” from Audion. The price of this machine is around €22,000.-. This machine is working from tube film or bags-on-a-roll. It easily forms pouches in-line before they are filled, optionally printed/labelled and sealed (Audion, 2018).

FIGURE 7-7, SPEEDPACK (AUDION, 2018)

7.2.3 Set Trioform knife

FIGURE 7-8 TRIOFORM KNIFE SET

The set that is needed for the Trioform knife contributes in total almost 85% towards the whole set production and because of that it is discussed separately. In total 30,000 sets are needed on a yearly base. The set consists out of two rings, bolts and nuts and a knife which are different for each set. These parts are depicted in Figure 7-8. Currently the parts are picked when needed, but Trioliet wants to make this set in advance. In this section possible options for the production of this set is discussed, where 30,000 sets per year are assumed.

When an operator makes the sets at Trioliet it costs around 20 seconds to pick one set, assuming bulk production. This means that it would take around 167 hours to produce the annual need of these sets. An employee of Trioliet costs €18.85 per hour making it a total of €3141.66 per year. Strictly speaking it costs no extra money when the operator can produce the sets during working hours, but when an extra employee is needed or the employee produces the sets in overtime the costs are relatively high.

Another option is hiring an employee of Larcom and let them pick the sets at Trioliet. It will probably take the same time after a small learning curve. This means that the same 167 hours are required to produce the annual need of this set. The costs of hiring an employee of Larcom lie around €10.- per hour, which makes it a total of €1670.- per year. The disadvantage is that extra working space for this employee is needed and an extra person walks in the Trioliet warehouse. The extra person has also an advantage, when another set is needed he/she can produces that set or help with other tasks.

The third option is outsourcing to Larcom. This means that Larcom does the set production at their location. Trioliet delivers the parts to Larcom and Larcom produce the sets. The costs of this option are €0.09 per set, making it a total of €2700.- a year. The disadvantage is that the parts have to be delivered to Larcom and the stock has to be sufficient. The advantage is that the production is done outside Trioliet, creating more space at Trioliet.

The last option is order pre-packed sets. Currently, the cost are €1.21 per set, ordered at MCB*. When ordering the parts at Würth* the cost of a pre-packed set is €1.26 resulting in €0.05 extra per set. For the total of 30,000 sets this results in approximately €1500.- per year. A major advantage is the same as for outsourcing, namely that no space is needed for the parts and no extra working space needed. A disadvantage in this case is another supplier, which brings double supply of the same underlying components or a complete switch of supplier.

How	Per set	Total
Employee Trioliet	€ 0.11	€ 3,141.66
Employee Larcom	€ 0.06	€ 1,670.00
Outsource to Larcom	€ 0.09	€ 2,700.00
Pre-packed purchase	€ 0.05	€ 1,500.00

TABLE 7-4, COST OF SET TRIOFORM KNIFE

* MCB and Würth are both metal suppliers and current partners of Trioliet.

7.3 Storing strategy

The conclusion from Section 6.4 is that the allocation of the parts is not optimal. Parts that are picked often are located far away from the I/O point while parts at locations close to the I/O point are barely picked. In this section an allocation policy is created to decrease the total travel distance and time.

The average number of picks per travel round is three. Especially in the pallet area the parts are difficult to handle and are often picked one by one. In the shelving area, parts are often picked together but because of repacking these parts are also picked in small amounts. With this information the COI strategy seems the most efficient allocation method.

The COI allocates parts to a storage location according to their popularity. Parts that are picked often are located close to the floor and close to the I/O point. This could be a good policy for Trioliet, but Trioliet makes use of two I/O points from where different orders are picked. Which order is picked at which side of the warehouse is known in advance, so making a percental distribution between the I/O points, as mentioned in literature, is not realistic.

To overcome the problem of the two I/O points, a combination of class-based and COI is used. The warehouse is divided into classes and within these classes the COI approach is used. The percentage of picks at spare parts and incoming goods is calculated and depicted in Table 7-5. From the table it can be concluded that 1119 parts are picked more than 75% at the spare parts I/O point and 1469 are picked more than 75% at the incoming goods I/O point.

Spare parts		Incoming goods	
100-75%	75-50%	50-75%	75-100%
1119	92	154	1469
1119	246		1469
39.48%	8.68%		51.83%

TABLE 7-5, PARTS IN WAREHOUSE

After analyzing the data the decision has been made to divide the warehouse into three parts.

- Spare parts side → parts that are picked more than 75% at the spare parts I/O point.
- Middle side → parts that are picked less than 75% at one of the two I/O points.
- Incoming goods side → parts that are picked more than 75% at the incoming goods I/O point.

The size of each class is dependent on the percentage of parts that are present in each class. Parts can be stored either in the pallet area or in the shelving area. Because of that, the two different storage areas are handled separately in the rest of this section.

Dependent on the total picks of the product, the parts are assigned to a location. Parts that are picked frequently are located close to the I/O point.

In Section 7.2.1.2 it has been concluded that the 22 parts that are needed in sets together from the pallet area should be located close to each other. These combinations will be seen as 'super parts' that need more than one pallet location. This restriction guarantees that these parts are located next to each other. These parts are located dependent upon the average picks of the parts within the set.

7.3.1 Pallet area

In the pallet area 834 parts are picked more than 10 times a year. These picks are divided over the two start locations as shown in Table 7-6. With this information the pallet area can be divided in the three different classes. The division that is made looks like this:

- 42% for the spare parts side.
- 11% for the middle side.
- 47% for the incoming goods side.

Spare Parts		Incoming goods	
100-75%	75-50%	50-75%	75-100%
350	43	47	394
350	90		394
41.97%	10.79%		47.24%

TABLE 7-6, PARTS PALLET AREA

The total amount of racks is 270 (all 9 layers high). 42% results into 113 racks for the spare parts side (blue), 11% results into 30 racks for the middle side 9 (white) and 47% results in 127 racks for the incoming goods side (brown). This results in the division depicted in Figure 7-9.

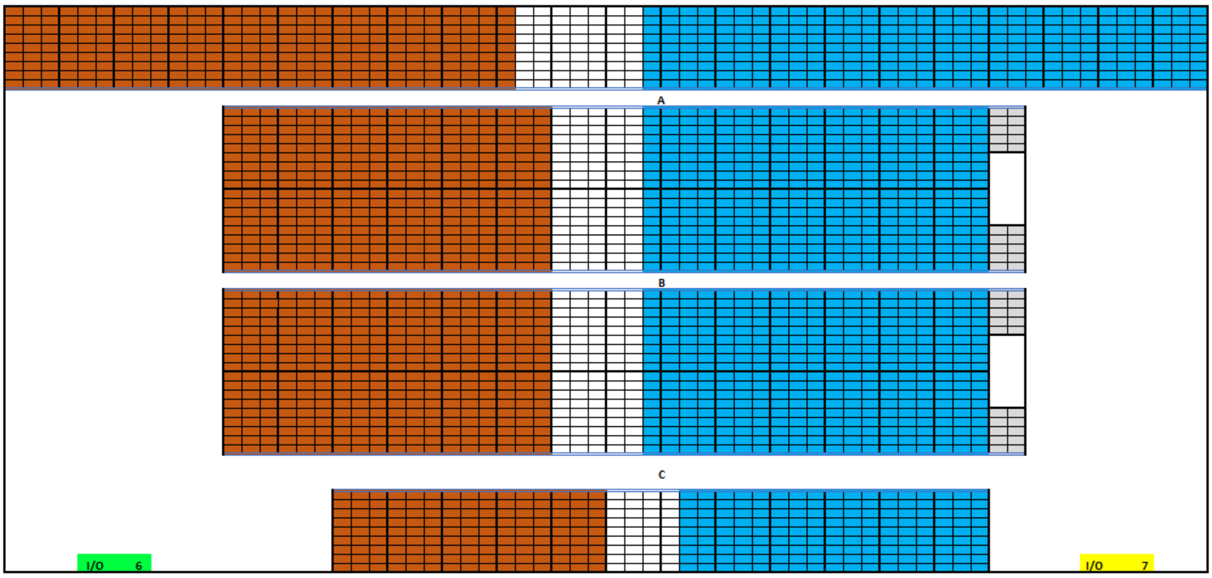

FIGURE 7-9, DIVISION PALLET AREA

Some information about the pallet area:

- The first three layers are accessible without the use of any equipment.
- Aisles A and B are only accessible with a reach truck.
- Aisle C is accessible with all equipment.
- Gray racks are currently used for specific products, that does not fit in the pallet area.

With this information a map with ranked locations is created. The first three layers are accessible by hand, therefore these locations are filled with numbers.

- The second layer is the most accessible, thus the first number is for the second layer.
- After that the first layer is the most accessible, so the second number is for the first layer.
- The third layer is the least accessible, therefore the third number is for the third layer.
- The closer the rack is to the I/O point, the higher the priority.
- Every part gets one pallet location and overstock is located at higher pallet layers.

With this ranking, the map in Figure 7-10 is created.

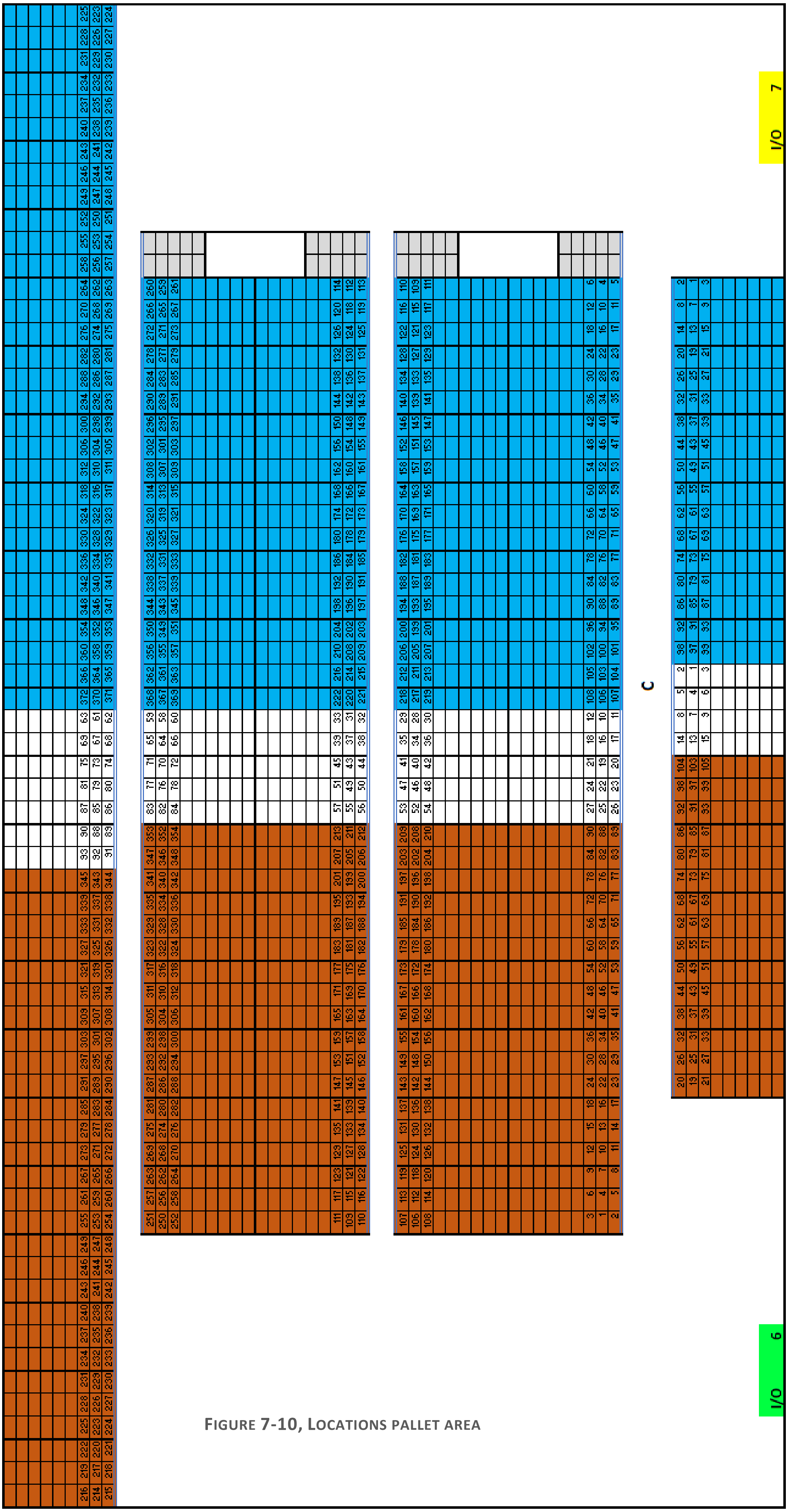

FIGURE 7-10, LOCATIONS PALLET AREA

As shown in Figure 7-10 most parts can be located in the first three layers of the pallet area. The rest of the parts can be located at the C aisle close to the I/O point.

There are a couple of parts that are heavy or difficult to handle and a pallet truck is needed to pick and move these parts. When these parts are located at the higher layers in the C aisles, all the parts that can be picked without the use of equipment can be located on the first three layers. This will minimize the use of equipment and makes the process more efficient.

Spare Parts		Incoming goods	
100-75%	75-50%	50-75%	75-100%
350	43	47	394
350	90		394
41,97%	10,79%		47,24%

TABLE 7-7, PARTS PALLET AREA

The parts are ranked starting with the parts that are picked the most. Parts that are picked 75% or more at spare parts get letter L (left), Parts that are picked 75% or more at incoming goods get letter R (right) and parts that are picked at both sides receive letter M (middle).

An example of the first 16 parts is depicted in Table 7-8 For example part 23808 is picked 56% at the spare parts department and 44% at the incoming goods department with 8274 as total picks. This part gets the first location in the middle department, location 1.

	2017			Spare parts		Incoming goods		
Article Nr.	Parts	Incoming	Total	100-75%	75-50%	50-75%	75-100%	Location
50411	1477	23411	24888	-	-	-	Left	1L
05818	16292		16292	Right	-	-	-	1R
30725	2871	8705	11576	-	-	-	Left	2L
23808	4674	3600	8274	-	Middle	-	-	1M
23661	5135	2394	7529	-	Middle	-	-	2M
X50107	200	6478	6678	-	-	-	Left	3L
23664	4403	1747	6150	-	Middle	-	-	3M
2017891	6106		6106	Right	-	-	-	2R
8400171	5597		5597	Right	-	-	-	3R
05945	5344		5344	Right	-	-	-	4R
84923	101	5222	5323	-	-	-	Left	4L
05819	5271		5271	Right	-	-	-	5R
X50102	101	5107	5208	-	-	-	Left	6L
X50335	34	5133	5167	-	-	-	Left	5L
86302	123	4940	5063	-	-	-	Left	7L
X50104	502	3832	4334	-	-	-	Left	9L

TABLE 7-8, NEW DIVISION PALLET AREA

Parts that cannot be picked without equipment can be located at the higher layers in the C aisles. This creates space for the last parts of the list that do not have a location yet.

For example the rims in Figure 7-11. These parts cannot be picked by hand, but are located at the first three layers. To pick these parts a reach truck is needed. Therefore interchanging this part with a part in a higher layer that can be picked by hand will reduce the total use of the reach truck.

FIGURE 7-11, PALLET AREA

7.3.2 Shelving area

In the shelving area there are in total 2000 parts that are picked 10 times or more. These picks are divided over the two I/O points, as depicted in Table 7-9. With this information the shelving area can be divided in three different classes.

- 38% for the spare parts side (blue).
- 8% for the middle side (brown).
- 54% for the incoming goods side (pink).

Spare Parts		Incoming goods	
100-75%	75-50%	50-75%	75-100%
769	49	107	1075
769	156		1075
38.45%	7.80%		53.75%

TABLE 7-9, PARTS SHELVING AREA

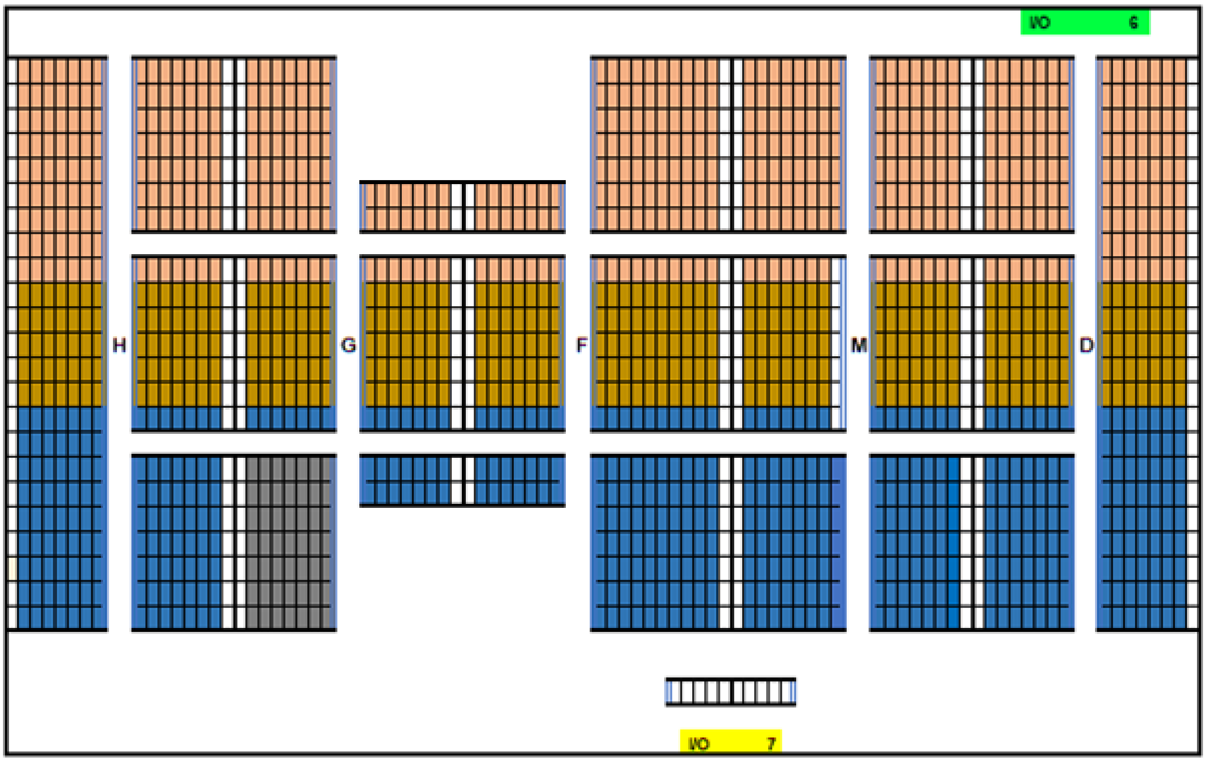

FIGURE 7-12, DIVISION SHELVING AREA

Some information about the shelving area:

- All layers except the highest layer are accessible without the use of a ladder.
- The fast pick area is used as 'extra' storage space for fast moving parts.
- The gray area is used for the sets discussed in Section 7.2.

With this information a map with ranked locations is created. Because the location of the bins within a shelf is dependent upon the size of the bin, the different shelves do not get a specific number. Large bins are, because of size and weight, located on the lower layers and small bins are located at the higher layers. Each shelf can store 24 parts on average. About 200 shelves are located on the ground floor area. 2000 parts are picked more than 10 times in the shelving area. All the parts picked more than 10 times can be located in 85 shelves.

One shelf can contain on average 24 different bins. An example of such a shelf is depicted in Figure 7-13. Dependent on the bin size, the bins are stored at different layers. This gives the shelving area a better organized look and makes lifting easier.

The parts are ranked starting with the most picked parts. Parts that are picked 75% or more at spare parts receive letter L (left), Parts that are picked 75% or more at incoming goods receive letter R (right) and parts that are picked at both sides get letter M (middle).

An example of the first 16 parts is depicted in Table 7-10. For example part 23660 is picked 39% at the spare parts department and 61% at the incoming goods department with accompanying total picks of 9790.

Because on average 24 bins can fit into one shelf, the first 24 parts are located in the first shelf. So the first 24 parts with location L are located in the first shelf of the incoming goods I/O point, the green rectangle in Figure 7-14.

FIGURE 7-13, SHELF WITH BINS

	2017			Spare parts		Incoming goods		
Article Nr.	Parts	Incoming	Total	100-75%	75-50%	50-75%	75-100%	Location
84953	69304	33668	102972	-	Middle	-	-	1M
84926	55242	16933	72175	Right	-	-	-	1R
84925	34336	16282	50618	-	Middle	-	-	2M
84942	32996	7796	40792	Right	-	-	-	2R
84487	880	14689	15569	-	-	-	Left	1L
33031	11568	2624	14192	Right	-	-	-	3R
91183		14090	14090	-	-	-	Left	2L
23660	3844	5946	9790	-	-	Middle	-	3M
86816	110	9374	9484	-	-	-	Left	3L
83921	6515	2484	8999	-	Middle	-	-	4M
91333		8108	8108	-	-	-	Left	4L
83916	2367	5037	7404	-	-	Middle	-	5M
84511	60	7127	7187	-	-	-	Left	5L
85142	975	5916	6891	-	-	-	Left	7L
83915	5493	1268	6761	Right	-	-	-	4R
33564	182	6464	6646	-	-	-	Left	6L

TABLE 7-10, NEW DIVISION SHELVING AREA

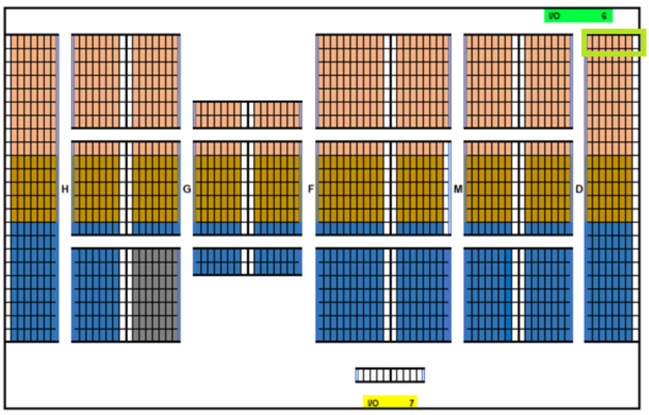

FIGURE 7-14, LOCATION OF FIRST 24 BINS (LEFT)

7.4 Order picking process

There are a couple of inefficiencies that occur during the picking process:

- Single order picking.
- Part picking, because it is heavy and difficult to handle parts.
- Picking equipment is unsuitable in pallet area.
- Packing of orders is time-consuming.
- Ladders in shelving area stand in the way.

Currently single order picking is performed, resulting in unnecessary travel time. A standard order consists out of parts from the shelving area and the pallet area. The parts in the pallet area can be divided in parts that are picked by hand and parts that are picked with the reach truck. Currently an operator takes a single order and start picking the parts. The operator just picks the parts and when needed makes use of a reach truck or a fork lift. A cart is used to bring the parts to the temporary storage location. In the shelving area the cart is well suited equipment, but for the pallet area other equipment and another picking policy could result in improvements regarding efficiency.

Three inefficiencies/solutions are discussed here. First another picking policy passed upon picking zones is discussed. Followed by a problem in the shelving area and ending with the equipment used in the pallet area.

Picking zones

The total pick area may be divided into picking zones so that each operator is dedicated to picking the parts only in his/her zone. When combining the different orders and dividing them into different picking zones an enormous efficiency improvement can be achieved. The warehouse can be divided into three zones:

- The shelving area → these parts are picked by hand.
- The first three layers of the pallet area → these parts can be picked by hand.
- The other layers of the pallet area → these parts are picked by a reach truck or fork lift.

This zoning can make the picking process a less time-consuming process. Due to the smaller area coverage by each picker, the advantages of such zoning are the familiarity of each picker with his/her zone, and travel time reduction (Jane & Liah, 2005). Another advantage is that one operator stays on the reach truck and thereby reducing the total travel and waiting time.

Ladders in shelving area

At this moment they make use of a ladder to pick parts from the upper layers. All the other layers are accessible without a ladder.

A disadvantage of the ladder is that it blocks the aisles. When an operator walks with a cart through the shelves, he/she constantly has to move alongside the ladders, see Figure 7-15.

A solution is a track ladder. This product rolls along a track installed on the shelf (Cssyses, 2018). The cart can pass this ladder. An example of a track ladder is depicted in Figure 7-16.

Another solution is to minimize the use of the highest layer for parts. The highest layer can be used for overstock, such that the use of a ladder is minimized. When the use of a ladder can be minimized the ladder can be located somewhere else.

FIGURE 7-15, LADDERS AT TRIOLIET

FIGURE 7-16, TRACK LADDER (CSSYSES, 2018)

Equipment used in pallet area

Currently a cart is used to pick the parts. The biggest problem is that this cart has little storage space for the relatively big parts in the pallet area. Another problem is the travel speed of the cart. The operator has to walk large distances which cost a lot of travel time. The last problem is that the maximum reach height is three layers.

An improvement would be the use of equipment that can lift a pallet, so double handling can be prevented. This equipment could also decrease the travel time and increase the storage space. There are a lot of different order pick trucks. The travel time, storage space and picking height are now discussed.

Travel time

Currently operators pick all the parts walking with a cart. According to Unicarriers (2017) transfer with a ride-on driver is 40% faster than a walking driver if the distance is about 25 meters (Unicarriers, 2017).

The pallet area of Trioliet has a total area of 750 square meter (50x15). So the use of a ride-on carrier can decrease the total travel time.

Storage space

The cart that is used at this moment has a surface of 85x50 centimeter. This cart has little storage space. When a truck is used, a pallet or other storage material can be used to increase storage space and possible storage options.

When introducing the picking truck, part picking is no longer a problem. There is enough space for parts and the parts can directly be located on/in the pallet. When the parts are directly stored in the pallet, double handling can be prevented.

Picking height

The standard low-level picking trucks can pick up until the third layer. Another option is the 'low-level picking truck with rising platform and forks'. This is a truck that can lift the operator and the pallet such that he/she can pick parts at an ergonomic working height and can pick parts at higher layers.

There are a lot of different picking trucks available, both with single and double forks. A couple of examples are depicted in Figure 7-17.

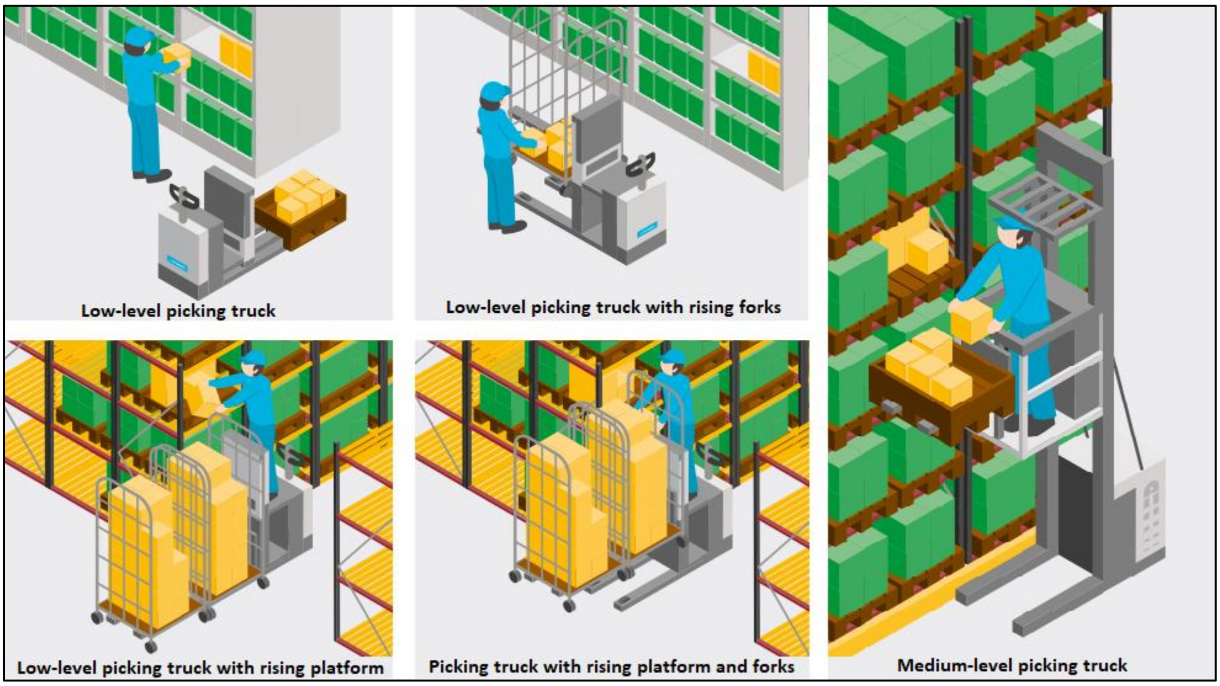

FIGURE 7-17, PICKING TRUCK (UNICARRIERS, 2017)

7.5 Investigate other option: Automation

There are four inefficiencies present in the storing system for small parts:

- A lot of ground space is needed to locate all the parts.
- There is a lot of travel time between the different parts.
- Parts are located on high layers, so a ladder is needed.
- Parts are located on a low and therefore not ergonomic working height.

A possible solution for these problems and inefficiency improvement could be a goods-to-person picking solution. As discussed in the literature there are a couple of different goods-to-person picking solutions. These solutions and there pros and cons are discussed here.

In the literature review three different goods-to-person principles are discussed: horizontal carousel, vertical carousel and VLM. Because the warehouse of Trioliet is quite high and ground space is scarce, the horizontal carousel is less interesting than the VLM and the vertical carousel.

The two principles that are interesting for Trioliet are the VLM and the vertical carousel. These two are discussed in this section and with the help of external companies different implementation options are analyzed. First a couple of advantages of both systems are addressed.

With these systems less ground space is needed to store all the parts. An example of a vertical carousel where 1500-2500 parts can fit in has a size of 3.420x1.670x8.028 meter, One carousel needs 5.7 square meters. With six of these vertical carousels all the parts can be located in one of these carousels. These six carousels need 34.2 square meters of floor space against 236 square meters at the moment, which is a reduction of 86%. In Figure 7-18 a possible new lay-out is depicted on scale.

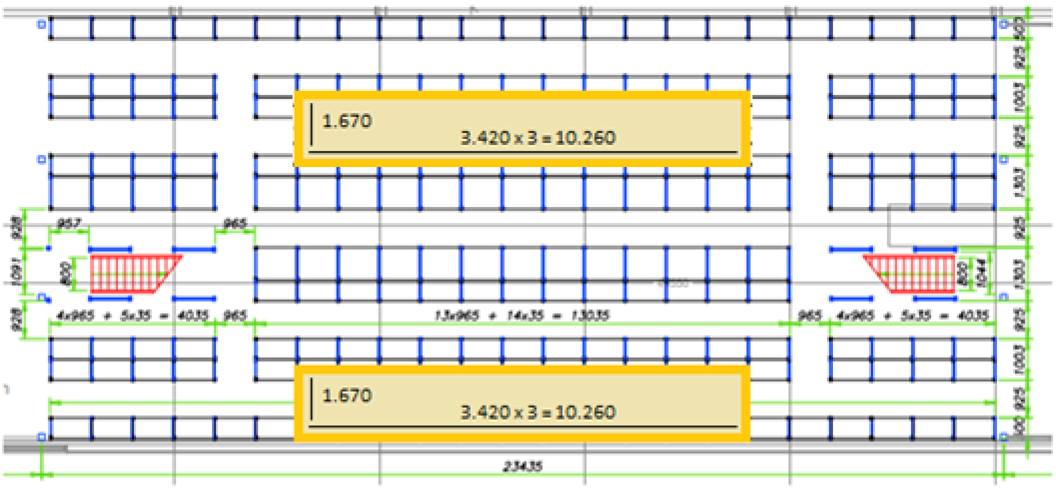

FIGURE 7-18, LOCATION NEW STORING SYSTEM

Another problem with the storing system in use is travel and searching time. This can be reduced with the use of a VLM or vertical carousel. Both of these goods-to-person picking solutions bring the parts to the operator, thus there is almost no travel distance. Besides that, the right layer is brought to the operator and thereby the searching time is minimized.

The last problem with the storing system is the different height of the layers. The goods-to-person principle brings the parts to the operator at an ergonomic working height. With this principle no ladder or other tool is needed.

Overall these goods-to-person picking solutions will solve all the problems mentioned in the old storage system. The two best goods-to-person picking solutions for Trioliet are the VLM and the vertical lift module. These principles and their pros and cons are elaborated further in the following section.

Vertical carousel

A vertical carousel is built with carriers attached in fixed locations to a chain drive. Movement is powered by a motor, which sends the carriers in the vertical loop around a track. This motor can drive forward and backward, depending on the next part needed.

A vertical carousel ranges from 2-4 meters wide and 1-2 meters deep. Designed for smaller product sizes, the carriers that store the inventory measure from 2-4 meters wide, 40-60 centimeters deep and maximum of 45 centimeters high.

FIGURE 7-19, VERTICAL CAROUSEL (SCHUSTER, 2018)

Vertical Lift Module

An VLM consists of two columns of trays with a mechanical extractor positioned in the center. This extractor travels between the stored trays, automatically locating and retrieving them when needed.

A VLM ranges from 1.5-4.5 meters wide and 2-3 meters deep. The trays that store the inventory range from 1-4 wide and 60-90 centimeters deep and a maximum of 70 centimeters high.

FIGURE 7-20, VERTICAL LIFT MODULE (SCHUSTER, 2018)

Vertical Carousel VS Vertical Lift Module

Height

- A vertical carousel starts at 2 meters and can reach up to 10 meters.
- A VLM starts at 2 meters and can reach up to 30 meters.

Load Capacity

- A vertical carousel can handle up to 650 kilogram per carrier.
- A VLM can handle up to 1000 kilogram per carrier.

Picking speed

- A vertical carousel can handle up to 200 units per hour.
- A VLM can handle up to 120 units per hour.

Layout

- In a vertical carousel the carriers have a fixed position. The shelf level within the carriers can be adjusted up or down, but not automatically.
- In a VLM the carriers are not fixed. Height sensors are used to measure how tall the parts are and the VLM stores the trays dynamically as close as one inch apart, to maximize storage density.

A vertical carousel is the best choice when the ceiling height is under 8 meters. Stored parts share relatively similar dimensions and parts can be picked without lift assistance.

A VLM is the best choice when the ceiling height is up to 30 meters. Stored parts are variable in size and weight, frequently changing inventory mix and heavy parts that require lifting assistant.

Trioliet uses six different sizes of bins to store all the parts. The sizes of the bins and the percentage of bins per size are depicted in Table 7-11.

Examples of possible goods-to-person options for Trioliet are discussed in Appendix I.

Bin	Depth	wide	Height	Percentage
1.	68	47	30	5%
2.	50	31	20	10%
3.	34	21	20	35%
4.	34	21	15	10%
5.	23	15	12	20%
6. Wurth	40	15	15	20%

TABLE 7-11, BINS USED AT TRIOLIET

7.6 Conclusion

In this chapter the problems are analyzed and possible solutions are discussed. The outcome of the different sections is summarized here.

Receiving process

A new desired situation is proposed for the receiving process. There are some pallet racks added which creates extra storage space. This extra storage space can be used for temporary storage. Another additional benefit is that the storage locations can get a location number, such that the operator can find the parts without searching.

Set production

For the set production a new allocation method is proposed. With this new allocation the parts are located closer to each other in order to reduce the total travel time. Furthermore, different options to make the set production less time-consuming are proposed.

Storage strategy

A new desired situation is proposed for the storage of parts. A combination of class-based storage and COI is created to minimize the total travel time from both I/O points. This is done for the pallet area and the shelving area.

Order picking process

For the order picking process new equipment and a new policy are proposed. A zone picking policy is advised to reduce the travel time. New equipment for picking parts from the pallet area is advised and possible solutions for the problem with the ladders in the shelving area are discussed.

Storage system small parts

New storage systems for small parts that seem interesting for Trioliet are the VLM and the vertical carousel. With help of external companies, goods-to-person storage systems are analyzed and proposed. These automatization options can replace the shelves in the shelving area eventually.

Chapter 8 - Solution Test

In the previous chapter solutions for the different problems are explained. With this information the fifth research question is answered: "What is the effect of the new order picking process and the new storage of parts". This chapter starts with testing the results of the extra pallet racks in the receiving area within Section 8.1. Furthermore, Section 8.2 discusses the results of the reallocation of the sets. Within Section 8.3 the new advised storage strategy is explained. Besides that, Section 8.4 discusses the solutions in the picking process. Lastly, in Section 8.5 a new storage system for small parts is explained and tested.

8.1 Receiving area

There are two inefficiencies recognized within the receiving process.

- Unnecessary search time because the documents are picked from the pallet and the pallet is located somewhere else. The second operator has to pick the documents and search for the box or pallet.
- Not enough temporary storage space. Boxes and pallets are located wherever there is space left. This results in a mess in the receiving area.

The solution that has been suggested is to build extra storage racks as depicted in Figure 8-1.

For the receiving of goods, a rack of three layers width and nine layers high is advised. This rack will be located at the left entrance of the logistic center (Y) as depicted in Figure 8-1. The other side of this rack can be used for extra storage space (Z). This other side (back side) is not easily accessible with a forklift (which are used for unloading the truck), so this side will not be used as temporary storage location but solely for extra storage space.

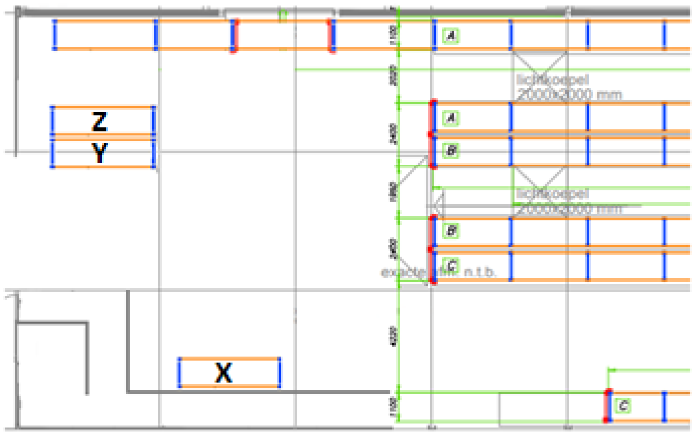

FIGURE 8-1, NEW PALLET RACKS

This storage rack creates (9x3=) 27 temporary (Z) storage locations and also 27 extra storage locations (Y). This solves both problems in the receiving area:

- The incoming goods can get a temporary storage location and thereby the searching time is significantly decreased.
- The receiving area is better organized and less ground space is occupied.

Another advice is to build a storage rack for pallets needed in production depicted by location X in Figure 8-1. Currently these pallets are stored at the ground floor and thus occupying a lot of ground floor and thereby creating chaos. With the introduction of this new pallet rack all pallets can be stored in this storage rack. Because of design and architectural issues the decision has been made to make use of a 4 layers in height rack. This storage rack creates (4x3=) 12 pallet locations.

The reach truck makes use of induction lines to stay on the track. Momentarily there are no induction lines for the new created pallet racks. To maximize the benefits of these new racks it is important to extend the induction lines such that the reach truck can easily pick in these pallet racks.

A possible disadvantage of the new racks is the decrease of working space. However, at this moment the ground space is almost always occupied. Furthermore in practice the total ground space that is occupied will decrease on average.

So the introduction of those new storage racks will result in extra storage space, less searching time and a decrease of total ground space used.

8.2 Set production

In Section 7.2 the inefficiencies are divided in three different sections. In this section, those are again discussed separately. In Section 8.2.1 the new allocation of the parts is analyzed. In Section 8.2.2 options for the manually set production are discussed. In Section 8.2.3 the sets with the Trioform knife are discussed.

8.2.1 Travel time

In Section 7.2.1 the decision has been made to reallocate the parts in the shelving area. A heuristic, with as starting point the OOS strategy, is created to allocate the parts in the shelving area. The result of this new allocation is that parts within a set are located close to each other. This results in a decrease in total travel and searching time.

As explained in Section 6.3 and depicted in Figure 6-4 the parts are located throughout the entire warehouse. When relocating the parts as discussed in Section 7.2.1, the allocation as depicted in Figure 8-2 arises. All parts, except for those in the fast pick area, are located in the first 9 shelves of the G aisle.

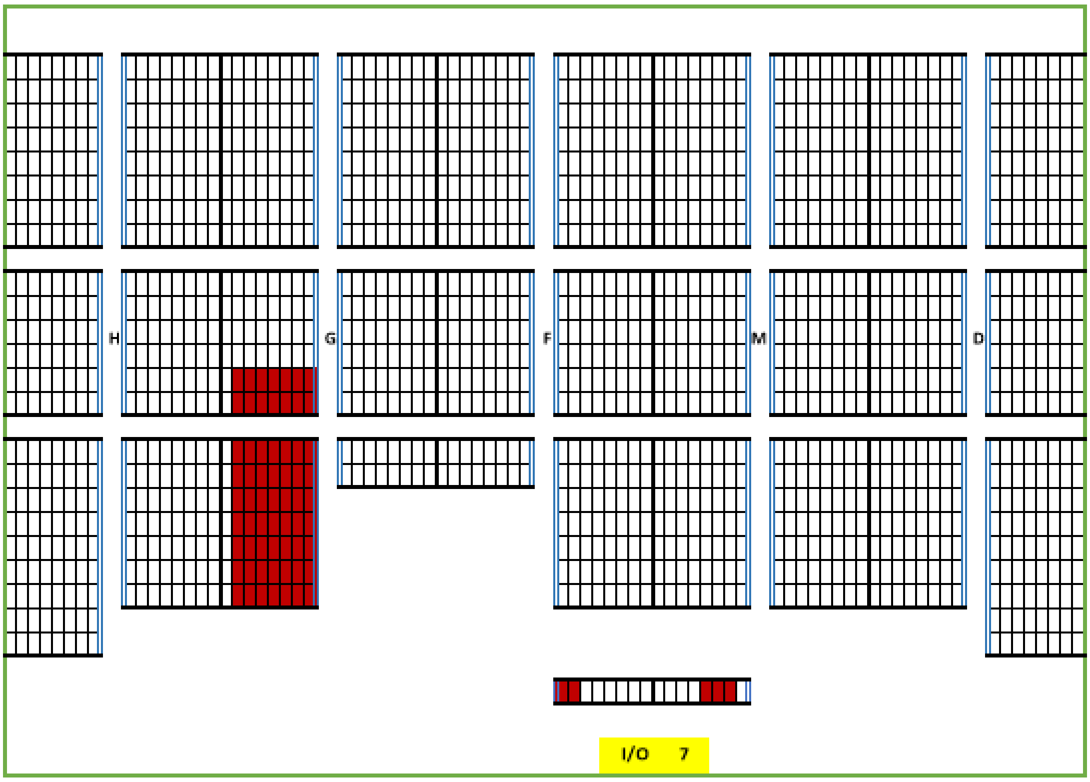

FIGURE 8-2, NEW HEATMAP SETS

With this new allocation both the searching time and the travel time decrease.

Searching time: As a result of the OOS all parts within a set are located as closely together as possible. When the bins are located next to or on top of each other the searching time is decreasing significantly.

Travel time: Before relocating the parts, the average travel distance to pick a set was 65 meters. With this new allocation the average travel distance is 28 meters. This is without any relocating in the pallet area. When this is done as well the total travel distance could be decreased even more.

8.2.2 Manually set production

For the manually set production there are two time-consuming processes, both the packing of parts and the product number writing. Multiple improvement options are opted in Section 7.2.2.

In total 4,937 sets are picked in 2017. The average picking time of these sets is 3.5 minutes making it a total picking time of approximately 288 hours a year. Assuming that the costs of one operator is €18.85 per hour, the cost for set production at this moment equals €5,428.80 per year.

FIGURE 8-3, WRITTEN PRODUCT NUMBER

An option to make the packing process more efficient is the introduction of automation options. Two options that were discussed are the introduction of a label printer and/or a packing machine.

A label printer will replace the handwritten product number as shown in Figure 8-3. This label printer decreases the total packing time and provides the sets with a more professional look. An example of a printed label is depicted in Figure 8-4. This label is printed with a label printer that Trioliet is using to label the bins, but with the introduction of this advised label printer the same label can be printed.

The purchase costs of a label printer lie around €290.- and the price of 100,000 labels lies around €250.-.

A label printer can be connected with an order to print all the labels needed for an order/set automatically. This can speed up the process enormously.

FIGURE 8-4, PRINTED LABEL

The label as depicted in Figure 8-4 is tested during the production of sets. Placing the stickers is a lot faster than writing the number, but printing the stickers requires time. Dependent on the number of stickers and the way of printing the stickers it can save more or less time.

An automatic packing machine could replace the ziplock bag. An example that is introduced in Section 7.2.2.3 is the Speedpack machine from Audion. This machine seals the bags and can print a label on the bag. An interpretation of this automatic packing machine is shown in the following video: https://vimeo.com/123070340 (Audion, 2018).

The purchase costs of this automatic packing machine equal approximately € 22,000.-. The price of the bags will decrease, because the foil used in the machine is cheaper than the ziplock bags that are used momentarily.

As shown in the video the packing process can become faster with the introduction of a packing machine. However, this cannot be quantified, because this depends on different factors like bulk production and size of the parts.

8.2.3 Set Trioform knife

As mentioned beforehand, the set with the Trioform knife is discussed separately. This is done because this specific set makes up 85% of the total sets picked in 2017. Approximately 30,000 sets are needed on a yearly basis. This is a relatively simple set and for this set the options discussed in Section 8.2.2 are worked out.

In Section 7.2.3 the options are discussed. The pros and cons are explained and the costs of each option are discussed. In Table 8-1 the different options and their costs are depicted.

How	Per set	Total
Employee Trioliet	€ 0.11	€ 3,141.66
Employee Larcom	€ 0.06	€ 1,670.00
Outsource to Larcom	€ 0.09	€ 2,700.00
Pre-packed purchase	€ 0.05	€ 1,500.00

TABLE 8-1, COST OF SET TRIOFORM KNIFE

As shown in Table 8-1 the cheapest option is to purchase pre-packed sets. No extra working space or logistic handlings are needed when this option is chosen. This seems the best option, so the decision is made to purchase a test batch.

An example of a box with this set is depicted in Figure 8-5. This set is delivered in a small cardboard box with a sticker, with product number and company name printed on it. This box can be sent directely to the customer.

FIGURE 8-5, TRIOFORM KNIFE SET

8.3 Storage strategy

In the previous chapters is explained that no mathematical or theoretical model is used to create the lay-out and allocate the parts. This has as a consequence that there is an inefficient allocation of parts. In Section 7.3 an allocation strategy is explained. In this section the results of this reallocation are analyzed and discussed.

This section is divided into two sections. In the first section the pallet area is discussed and in the second section the shelving area is discussed.

8.3.1 Pallet area

A heatmap is created for parts that are picked within the pallet area. This heatmap is depicted in Figure 8-6.

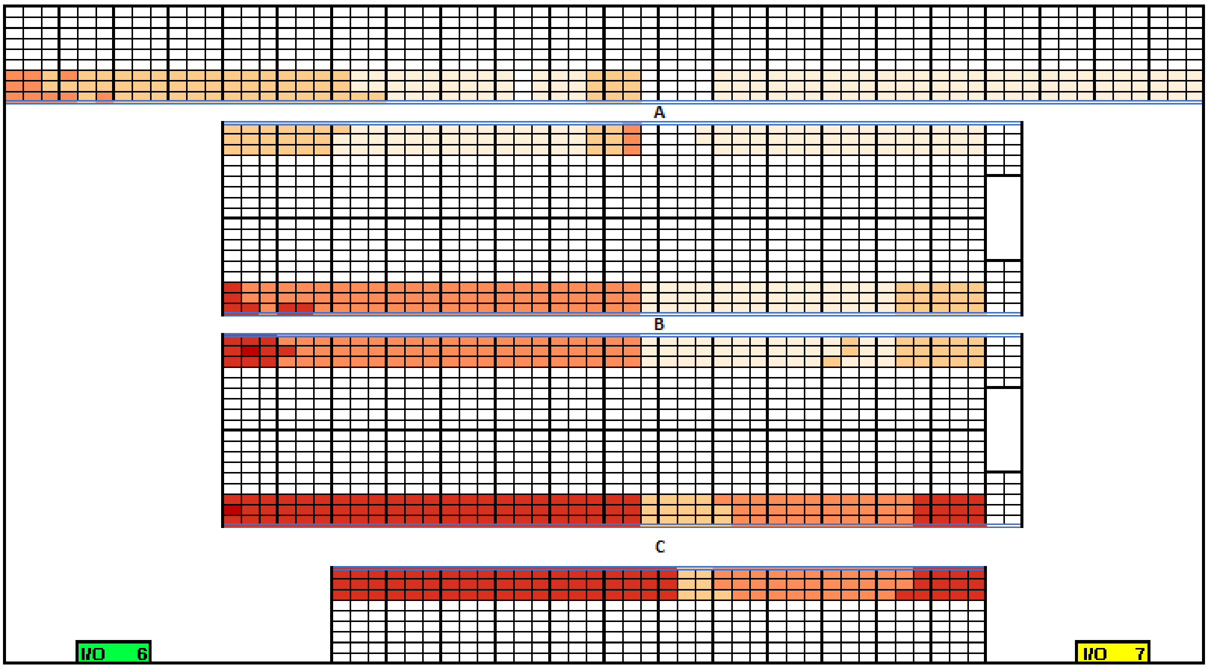

FIGURE 8-6, NEW HEATMAP PALLET AREA

The I/O points are located at the left (I/O point 6, incoming goods) and right (I/O point 7, spare parts). There are three aisles present in the pallet area and the racks are nine layers high. In the old situation there are two problems with the allocation of the parts, which are the following:

- Parts are located all over the warehouse, thereby creating unnecessary extra travel time.
- Parts are located at high layers, because of this the reach truck is often required.

In the new situation all parts that are picked often and can be picked by hand are located in the first three layers of the pallet racks. This decreases the need for the reach truck and furthermore decreases the total travel time.

Besides that, parts that that are often picked are located close to the I/O points. As shown in the heatmap, the parts that are mostly picked are located in the C aisles which is close to the I/O points.

<= 10,	
> 10,	
> 50,	
> 100,	
> 500,	

TABLE 8-2, LEGEND

The two I/O points are discussed separately and two heatmaps are created for both I/O points respectively. These heatmaps are divided for the two I/O points.

8.3.1.1 I/O point pallet area spare parts

A heatmap is created for parts that are picked from the spare parts I/O point (7) in the pallet area. This heatmap is depicted in Figure 8-7.

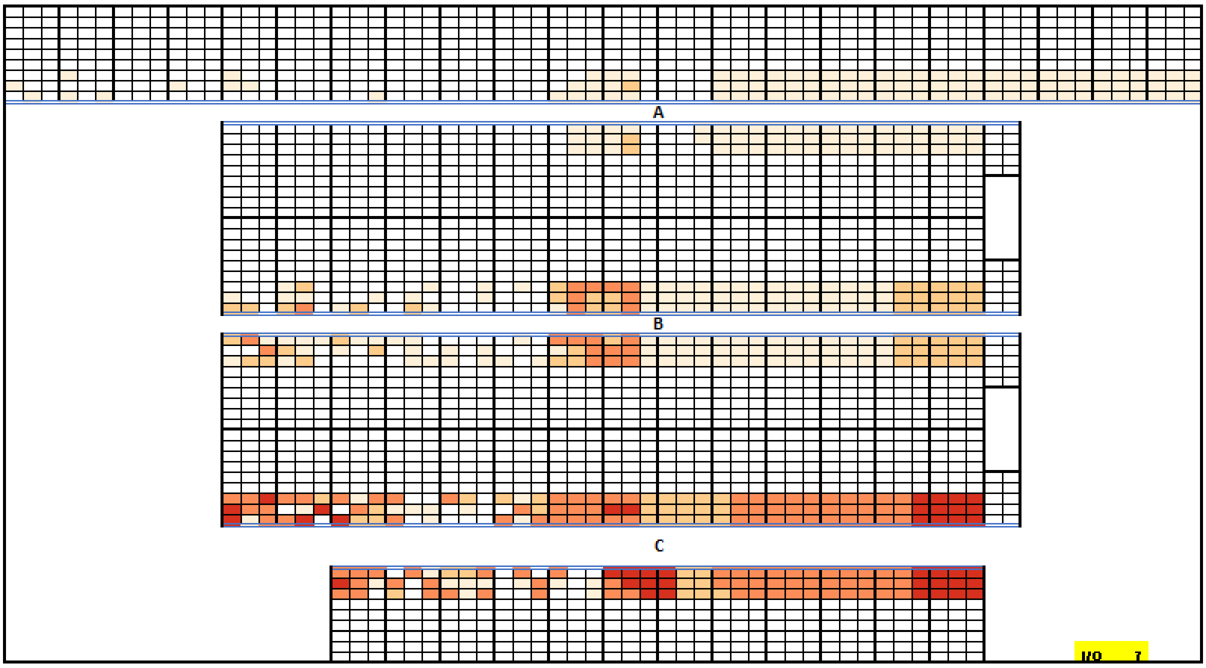

FIGURE 8-7, NEW HEATMAP PALLET AREA, SPARE PARTS

In this heatmap the picks from the spare parts I/O point are depicted. The heatmap is created with the same data that is used in Figure 6-11.

This heatmap is created on the basis of the rules drawn up in Section 7.3.1. Parts that are picked frequently are located close to the floor (first three aisles) and doors (I/O point 7). The allocation is done on the basis of Table 7-8 and Figure 7-10.

<= 10,	
> 10,	
> 50,	
> 100,	
> 500,	

TABLE 8-3, LEGEND

When comparing the heatmap of Figure 6-11 with the heatmap in Figure 8-7, the parts are located closer to the I/O point and more parts are located on the lower layers.

Reach truck

In the old situation, 20,662 of the total picks are performed at a layer that is not accessible without the use of a reach truck. This makes up approximately 8.5% of the total picks. In the new situation this can be reduced to almost zero for the small parts in the pallet area.

Travel distance

The average travel distance in the old situation is 40.8 meters. In the proposed new situation the travel distance is 29.4 meters. This is a travel distance reduction of almost 27.9%. A part of the excel file used to calculate the average distances is depicted and explained in Appendix K.

Layer	Parts picked
0	44650
1	140935
2	27988
3	11140
4	8537
5	3699
6	5284
7	2887
8	255
9	0
Total	**245375**
Reach truck	20662

TABLE 8-4, PICKS WITH REACH TRUCK

8.3.1.2 I/O point spare parts pallet area

A heatmap is created for parts that are picked from the spare parts I/O point (6) in the pallet area. This heatmap is depicted in Figure 8-8. This heatmap is designed according to the allocation rules set up in Section 7.3.1.

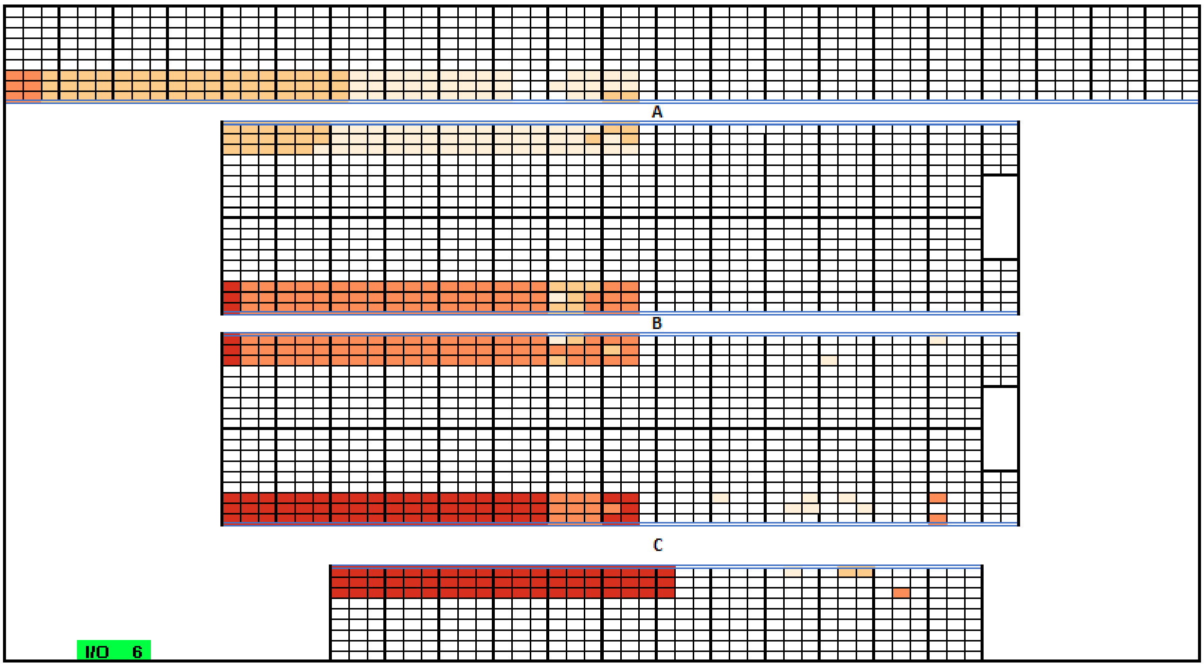

FIGURE 8-8, NEW HEATMAP PALLET AREA, INCOMING GOODS

In this heatmap the picks from the spare parts I/O point are visualized. The heatmap is computed with the same data as used in Figure 6-13.

This heatmap is created on the basis of the rules drawn up in Section 7.3.1. Parts that are picked frequently are located close to the floor (first three aisles) and doors (I/O point 7). The allocation is done on the basis of Table 7-8 and Figure 7-10.

<= 10,	
> 10,	
> 50,	
> 100,	
> 500,	

TABLE 8-5, LEGEND

When comparing the heatmap of Figure 6-13 with the heatmap in Figure 8-8 the parts are more located close to the I/O point and more parts are located on the lower layers.

Reach truck

In the old situation 4,770 of the total picks are done at a layer that is not accessible without the use of a reach truck. This is around the 3.1% of the total picks. In the new situation this can be reduced to almost zero for the small parts in the pallet area.

Travel distance

The average travel distance in the old situation is 45.7 meters. In the new situation the travel distance is 26.7 meters. This is a travel distance reduction of almost 42.2 %.

Layer	Parts picked
0	17060
1	122625
2	8064
3	3602
4	1178
5	915
6	816
7	1540
8	321
9	0
Total	**156121**
Reach truck	4770

TABLE 8-6, PICKS WITH REACH TRUCK

8.3.2 I/O point shelving area

A heatmap is designed for parts that are picked in the shelving area. This heatmap is depicted in Figure 8-9.

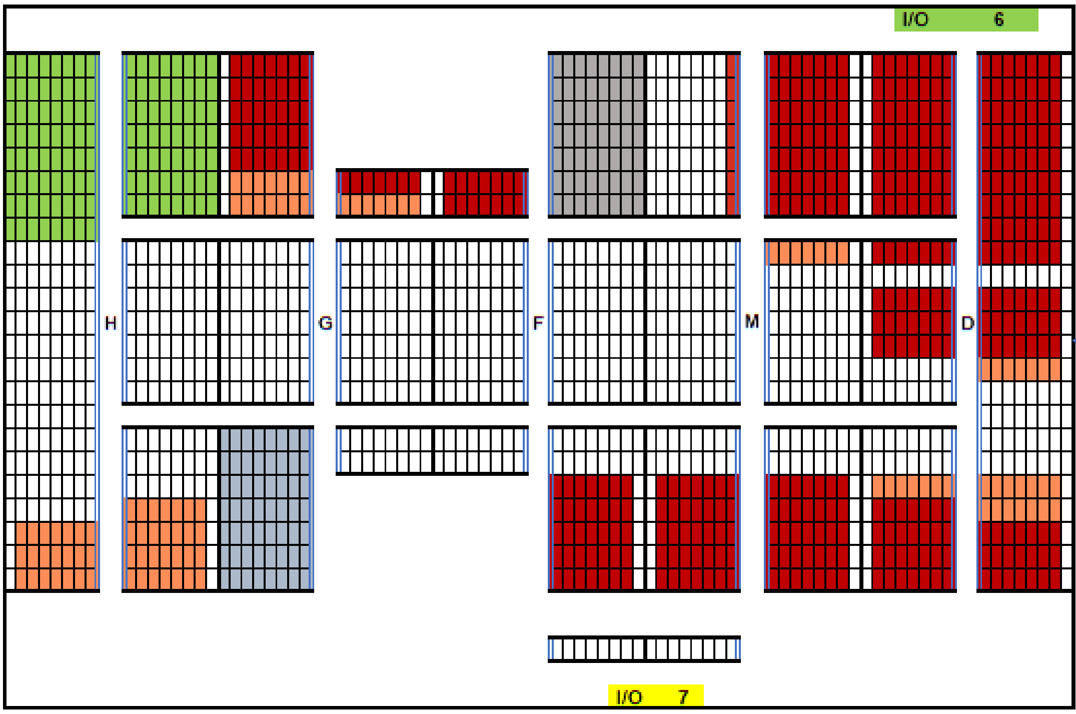

FIGURE 8-9, NEW HEATMAP SHELVING AREA

The I/O points are located at the upper-left (I/O point 6, incoming goods) and lower-left (I/O point 7, spare parts). There are five aisles in the shelving area, two cross-aisles and the racks contain eight layers in height. The green, gray and blue area are used for other purposes:

- The green area is left empty for the stickers.
- The gray area consists out of closed shelves for valuable articles.
- In the blue area all sets are located.

<= 10,	
> 10,	
> 50,	
> 100,	
> 500,	

TABLE 8-7, LEGEND

In the old situation there were three problems with the allocation of the parts:

- Parts are located all over the warehouse, thereby creating unnecessary extra travel time.
- Parts are located at high layers; therefore ladders are needed to pick the parts.
- Parts are located on the first or second floor, creating unnecessary extra travel time.

In the new situation the parts that are picked often are located at the ground floor and close to the I/O points. Each shelf contains 24 bins and dependent on the picks at each side of the I/O point the bins are located in one of the three zones.

	2017			Spare parts		Incoming goods		
Article Nr.	**Parts**	**Incoming**	**Total**	**100-75%**	**75-50%**	**50-75%**	**75-100%**	**Location**
84953	69304	33668	102972	-	Middle	-	-	1M
84926	55242	16933	72175	Right	-	-	-	1R
84925	34336	16282	50618	-	Middle	-	-	1M
84942	32996	7796	40792	Right	-	-	-	1R
84487	880	14689	15569	-	-	-	Left	1L
33031	11568	2624	14192	Right	-	-	-	1R

TABLE 8-8, EXAMPLE OF NEW ALLOCATION PARTS SHELVING AREA

The two I/O points are discussed and two heatmaps are created for those two I/O points. In the following part those two I/O points are discussed separately.

8.3.2.1 I/O point spare parts shelving area

A heatmap is designed for parts that are picked from the spare parts I/O point in the shelving area. This heatmap is depicted in Figure 8-10. This heatmap is computed according to the allocation rules created in Section 7.3.1.

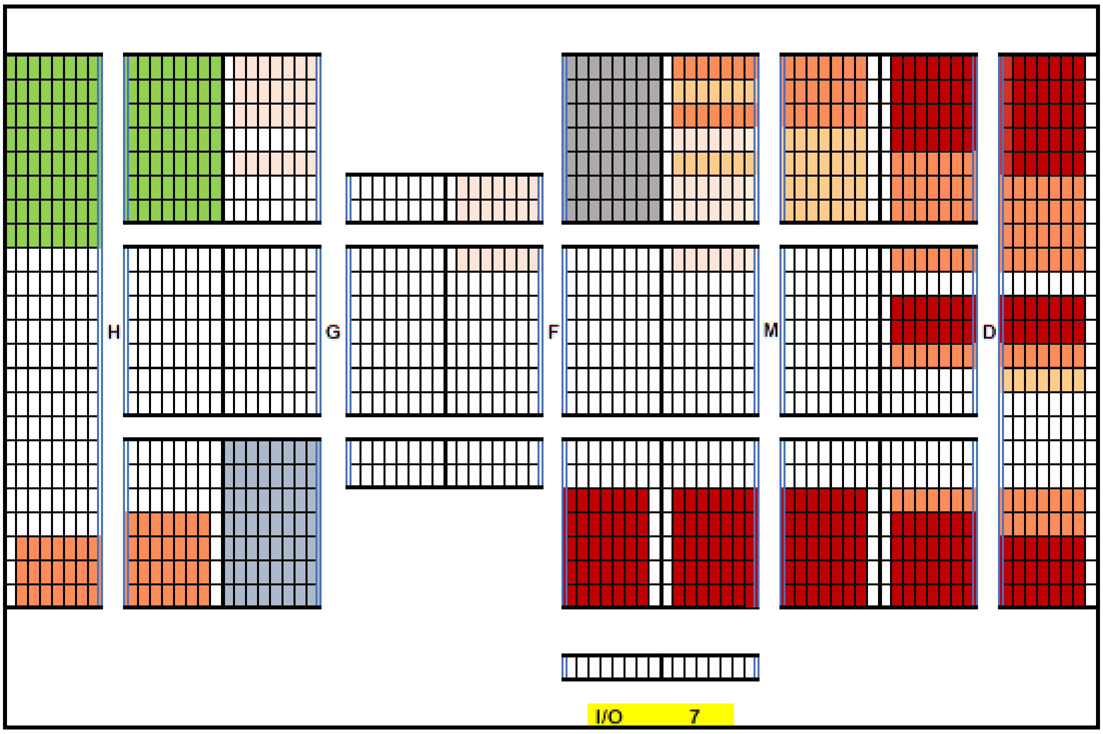

FIGURE 8-10, NEW HEATMAP SHELVING AREA, SPARE PARTS

In this heatmap the picks from the spare parts I/O point are depicted. The heatmap is visualized with the same data that is used in Figure 6-12.

This heatmap is created on the basis of the rules drawn op in Section 7.3.1. Parts that are often picked are located close to the floor (ground floor) and doors (I/O point 7). The allocation is done on the basis of Table 7-12 and Figure 7-10.

<= 10,	
> 10,	
> 50,	
> 100,	
> 500,	

TABLE 8-9, LEGEND

When comparing the heatmap of Figure 6-12 with the heatmap in Figure 8-10 the parts are located closer to the I/O point and more parts are located on the lower layers. Parts that are picked often and located at the first or second floor are relocated to the ground floor.

Travel distance

The average travel distance in the old situation is 18.4 meters. In the new situation the travel distance is 15.3 meters. This is a travel distance reduction of almost 16.8 %

Ladders

As mentioned in Section 7.4 one of the problems in the shelving area are the ladders that block the aisles constantly. An option that was suggested is to use the upper layer for overstock, such that the use of the ladder can be minimized. This is implemented in the heatmap. The highest layer is left empty and can now be used for overstock. As a consequence the ladders can be located outside the shelving area and just grabbed when needed.

8.3.2.2 I/O point incoming goods shelving area

A heatmap is computed for parts that are picked from the spare parts I/O point in the pallet area. This heatmap is depicted in Figure 8-11. This heatmap is created according to the allocation rules created in Section 7.3.1.

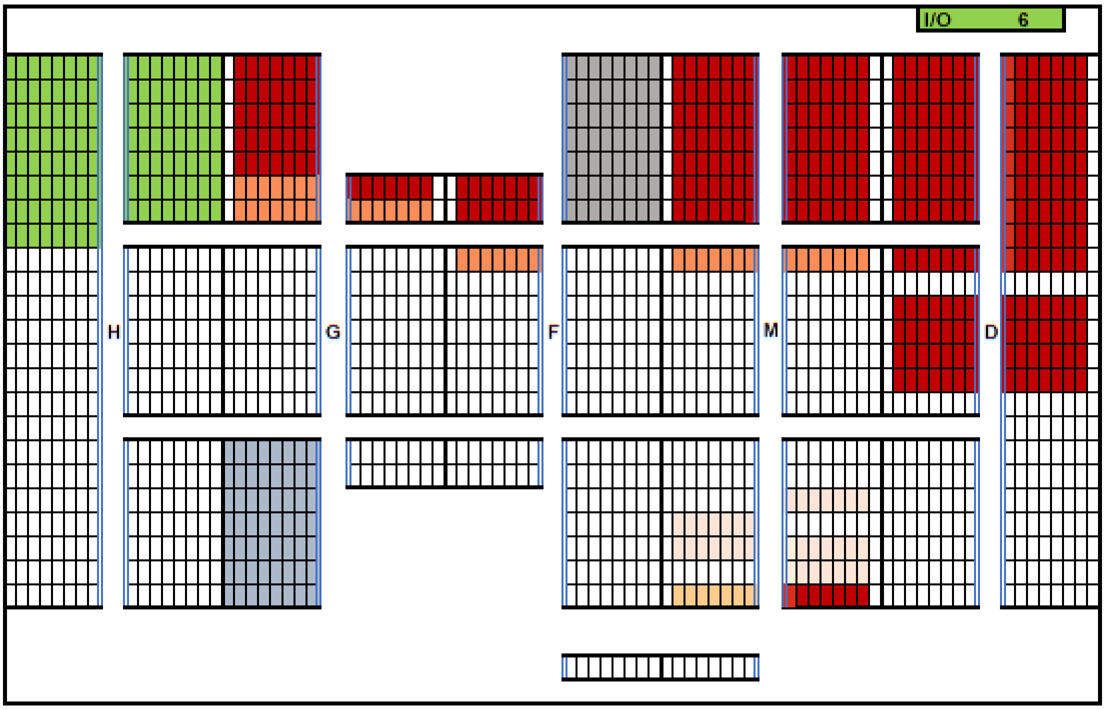

FIGURE 8-11, NEW HEATMAP SHELVING AREA, INCOMING GOODS

In this heatmap the picks from the spare parts I/O point are depicted. The heatmap is created with the same data that is used in Figure 6-14.

This heatmap is created on the basis of the rules drawn up in Section 7.3.1. Parts that are picked often are located close to the floor (ground floor) and doors (I/O point 6). The allocation is done on the basis of Table 7-12 and Figure 7-10.

<= 10,	
> 10,	
> 50,	
> 100,	
> 500,	

TABLE 8-10, LEGEND

When comparing the heatmap of Figure 6-14 with the heatmap in Figure 8-11 the parts are located closer to the I/O point and more parts are located on the lower layers. Parts that are picked often and located at the first or second floor are relocated to the ground floor.

Travel distance

The average travel distance in the old situation is 17.6 meters. In the new situation the travel distance is 11.8 meters. This is a travel distance reduction of almost 32.9 %

Ladders

As mentioned in Section 7.4 one of the problems in the shelving area are the ladders that block the aisles constantly. An option that was suggested was to use the upper layer for overstock, so that the use of the ladder can be minimized. This is implemented in the heatmap, the highest layer is left empty and can now be used for overstock. As a consequent the ladders can be located outside the shelving area and just grabbed when needed.

8.4 Order picking process

In this section, two different elements are discussed. In the first section the picking zones are discussed. In the second section the equipment used in the pallet area is discussed.

In this section no quantified solution is explained. The options mentioned and explained in this article cannot be tested easily so that is the reason that they are not tested in practice. The pros and cons of the different options are explained and discussed in this section.

8.4.1 Picking zones

In Section 7.4 it is advised to divide the warehouse in different picking zones. This results in a couple of possible benefits:

- The familiarity of each operator with his/her zone, due to smaller area coverage by each operator.
- Reduction in walking distance, because one operator has to cover a smaller area.
- Less exchanging time, one operator can stay on the reach truck.

A disadvantage of this zoning is that more communication is needed because orders are picked separately. The orders have to be combined later when all parts are picked.

In Section 7.4 the warehouse is divided into three zones, but after some testing and discussing it is decided to start with two zones:

- The shelving area and first three layers of pallet area, where these parts are picked by hand.
- The other layers of the pallet area, where these parts are picked by a reach truck.

The most time is wasted with the searching and waiting for the reach truck and switching of driver of the reach truck. When the same person stays on the reach truck and picks all the parts needed for both sides of the warehouse the efficiency will be improved significantly.

At a later stage, when this zoning is a success, the zones can be extended to three zones, as explained in Section 7.4.

8.4.2. Equipment used in pallet area

Momentarily a cart is used to pick all parts, both in pallet area and in the shelving area. A problem with this cart is that there is little storage space and that the operator has to walk relatively large distances.

To solve this problem a picking truck is advised. This picking truck has a couple of benefits:

- The operator can travel faster on a picking truck and the operator does not have to walk.
- The picking truck can transport one or even two pallets, which solves the storage problem.

As shown in Figure 7-17 there are also picking trucks with rising platform. When a truck with rising platform is used parts can be picked from higher layers by the same operator with the same truck. This can save time and the zones can be divided differently.

In Section 8.3.1 the first three layers of the pallet area are allocated, because these are reachable without the use of a reach truck. When a picking truck with rising platform is used this zone can be extended to the fourth or even to the fifth layer.

8.5 Investigate other option: Automation

In Section 7.5 are two different goods-to-person storage systems discussed, the vertical carousel and the vertical lift module. The benefits of the implementation of a goods-to-person storage system are hard to quantify, but on the basis of company visits and videos some benefits are quantified but first some facts are discussed. The information in this section is created with the help of H. Mosterd from Kardex Remstar (Mosterd, 2018).

- **Ergonomic design:** Ordered parts are automatically conveyed to the economic designed access opening, what minimized the chance of injuries.
- **Less manpower required:** The parts needed are automatically brought to the operator, saving travel and searching time.
- **Save ground space:** As explained in Section 7.5, 86% less ground space is needed when introducing a goods-to-person storage system.
- **Improved safety:** Shutter doors protect both the operator and the goods. The doors close when the system is moving or when it is not in use.
- **Precision:** Integrated pick-to-light systems, barcode readers and software interfaces guarantee a high level of precision.

As depicted in Figure 8-12, traveling is the most time consuming process in a traditional warehouse. With the introduction of a goods-to-person storage method this traveling is reduced enormously and the picking process becomes the most time consuming process.

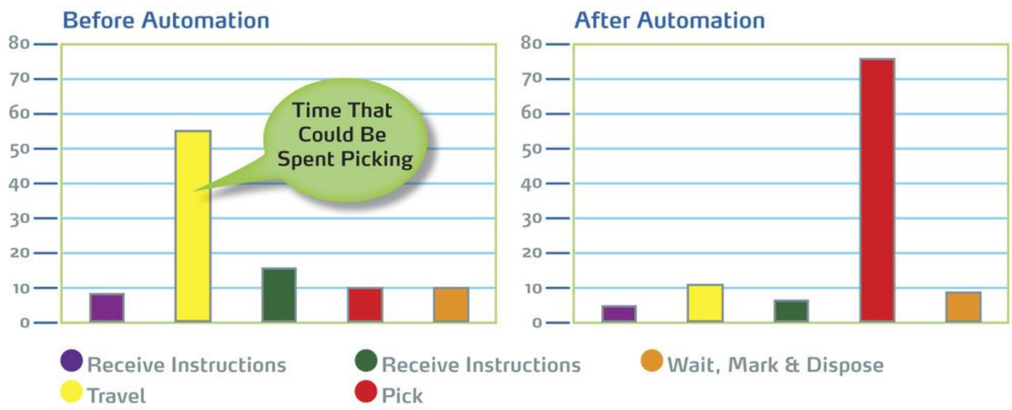

FIGURE 8-12, GOODS-TO-PERSON AUTOMATION (KARDEX REMSTAR, 2018)

With the help of a video of an implemented VLM solution the average picking time is calculated. This video is from a company in the field of hydraulic and pneumatic components. Parts are picked, packed and a sticker with product information is printed, as done at Trioliet.

Three VLM's are built at company X with at the other side a rack for maximum six bins. The operator picks the parts, locks the bags and puts an sticker on the bag. In the meantime the VLM brings another tray and the operator can start picking again. On average the operator picks around 180-200 parts per hour. At this moment, one operator can pick around 70-80 parts per hour in the shelving area.

The introduction of a goods-to-person storage method can improve the efficiency enormously and the ground space occupied is reduced. Further, the working environment for the operator gets safer and the precision improves.

In collaboration with Hänel and Kardex Remstar two implementation options are discussed. In collaboration with Hänel two possible goods-to-person options are worked out in Appendix I. In collaboration with Kardex Remstar an implementation plan for three vertical lift modules is created, this is worked out in Appendix J.

8.6 Summary solution test

In this chapter the solutions are tested and discussed. The outcome of the different sections is summarized here.

Receiving process

A new desired situation is proposed for the receiving process. There are some pallet racks added which creates extra storage space for incoming goods and production pallets.

No quantified data is computed, but after interviews with those involved and observing the process it can be concluded that the pallet racks will improve the efficiency at incoming goods and decrease the average occupation of the ground floor.

It can be said that the new storage racks will result in extra storage space, less searching time and a decrease of total ground space used.

Set production

For the set production a new allocation is proposed. With this new allocation the parts are located closer to each other and thereby the total travel time is reduced.

This new allocation will decrease the travel distance from 65 meters per set to 28 meters per set. Besides that, the searching time decreases because a lot of parts are located next to or close to each other.

Furthermore, the manual set production is discussed. A label printer and an automatic packing machine are discussed, but no conclusions are attached to this.

Storage strategy

A new desired situation is proposed for the storage of parts. A combination of class-based storage and COI is created to minimize the total travel time for both I/O points. This is done for the pallet area and the shelving area.

Pallet area: With this new storage strategy the travel distance from both I/O points decreases and the usage of reach truck is minimized.

- For I/O point 7 the travel distance reduces from 40.8 meter to 29.4 meter, which is a reduction of 27.9%
- For I/O point 6 the travel distance reduces from 45.7 meter to 26.7 meter, which is a reduction of 41.6%

Shelving area: With this new storage strategy the travel distance from both I/O points decreases and the usage of ladders is minimized.

- For I/O point 7 the travel distance reduces from 18.4 meter to 15.3 meter, which is a reduction of 16.8%
- For I/O point 6 the travel distance reduces from 17.6 meter to 11.8 meter, which is a reduction of 32.9%

Order picking process

For the order picking it is decided to start with two picking zones. This reduces the searching and waiting time for reach truck. These two zones are:

- The shelving area and first three layers of pallet area, which are picked by hand.
- The other layers of the pallet area, which are picked by a reach truck.

Furthermore, the equipment used in the pallet area is discussed, but no conclusions are attached to this.

Storage system small parts

With the help of external companies some benefits are summed up. At this moment 70-80 picks are done per hour, with the implementation of a goods-to-person storing system this can become 180-200 picks per hour. Further, the working environment for operators gets safer and the precision improves.

Chapter 9 - Implementation and maintenance

In Chapter 7 the solution design is created and in Chapter 8 these designs are tested. With this information the sixth research question is answered: "How can Trioliet improve their processes based on the results found". This chapter starts with an implementation plan for the extra pallet racks in Section 9.1. Furthermore, in Section 9.2 a reallocation plan for the sets is explained. Besides that, Section 9.3 explains the new storage allocation that is advised. In Section 9.4 the advice for a new picking process is explained. This chapter will end with a future plan for the implementation for a goods-to-person storage system in Section 9.5.

9.1 Receiving process

As discussed and concluded in Section 8.1 the building of additional pallet racks will create a better organized working environment and on average less working space is occupied with temporary stored pallets. The newly built pallet racks are once again depicted in Figure 9.1 and explained below.

One pallet rack is built at **location X**. This storage rack will create 3*4 = 12 temporary storage locations. This pallet rack is for temporary storage of production. When production sends an order these parts are packed in a pallet and, when ready, sent to production. These pallets are stored at location X until they are sent to production.

Another pallet rack is built at **location Y**. This pallet rack will create 3*9 = 27 temporary storage locations for incoming goods. When a truck is emptied these parts/pallets get a temporary storage location in location Y. It is important that these parts receive a location number, such that the operator can find the location when he/she brings the parts to their warehouse location.

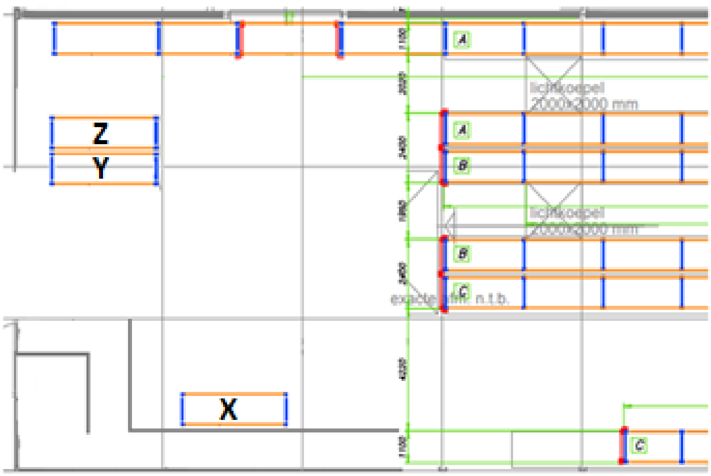

FIGURE 9-1, NEW BUILT PALLET RACKS

As additional benefit, an extra pallet rack is built at **location Z**. This is used as an extra storage possibility. This storage rack will create 3*9 = 27 extra storage locations.

The reach truck makes use of induction lines to stay on the track. Currently there are no induction lines for the newly created pallet racks. To maximize the benefits of these new racks it is important to extend the induction lines, in order for the reach truck to easily pick in those pallet racks.

For the maintenance aspect it is important that the pallet racks are strictly used for what they are built for:

- Location X is used for temporary storage of production orders.
- Location Y is used for temporary storage of incoming goods.

When the racks are used for other purposes, the same problems will occur. With as accompanying problem that even less ground space is available like before.

9.2 Set production

For the set production a couple of problems/solutions are discussed. For the implementation phase, the reallocation of the parts is discussed. Besides that, some advices regarding the set production are given.

9.2.1 Reallocation of set parts

For the reallocation of the parts within the sets a variant of the order-oriented slotting method is created in Section 7.2.1. This heuristic is implemented in the AIMMS software and an allocation per shelf is created. This allocation is depicted in Table 7-2. In Section 8.2.1 it is concluded that this new allocation results in a travel distance reduction of 56.9% and the searching time is thereby also decreased.

The allocation as explained in Section 7.2.1 is advised. First, the first nine layers of the G aisle need to be emptied as depicted in Figure 8-2. Thereafter the shelves can be filled.

In Table 7-2 the results of the heuristic are depicted. The first 24 parts (red) are allocated to the first shelf (red shelf in Figure 9-2), the second 24 in shelf two, etcetera.

There are some restrictions concerning the filling of the shelves.

- Bins are located within a shelf according to their size.
- When a bin cannot fit in a shelf, locate the bin in the next or previous shelf.
  In each shelf there is space for 27 bins, with the heuristic 24 bins are allocated on each shelf, so most bins fit in the shelf as depicted in Table 7-2. When a bin does not fit on the allocated shelf, allocate the bin to the previous or next shelf.

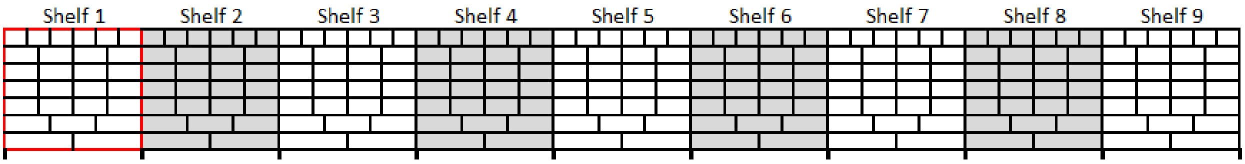

FIGURE 9-2, REDESIGN SETS SHELVING AREA

With this new allocation the mutual distance between the parts in the same set is minimized. There are two advices regarding the maintenance when this new allocation is implemented:

- When a new set is introduced, the underlying parts need to be located in one of these 9 shelves. When these 9 shelves are fully occupied a tenth shelf has to be introduced.
- The heuristic must be updated once a year. New data per set should be gathered and the heuristic needs to run. This updated heuristic needs to be implemented to keep the allocation of parts near optimal.

9.2.2 (Semi-) Automation

In Section 7.2 the label printer and a packing machine are evaluated. Both automation options can speed up the set production, but no quantified answer is provided in Chapter 8. In this section a small implementation plan is given for these automation options.

Label printer: At first, the label printer needs to print labels for the different sets. The sets are produced at the spare parts department, so this label printer should be located close to the computer of spare parts. Firstly, the labels are printed manually, but in the future this can be done automatically. When this is done automatically this will improve the process and reliability (when all stickers are used the set is complete).

Given the low purchase price (€290.-) and low label cost (100,000 labels for €250.-) this is a small investment that can and will result in efficiency improvement and a more professional look (as described in Section 8.2).

Packing machine: The packing machine is meant to be for the production of sets at the spare parts department. When a packing machine without a printer (for the labels) is purchased, the machine has to be located close to the label printer and computer. The packing machine has to be located at a location with enough working space and close to the shelving area.

9.3 Storing parts

As discussed and concluded in Section 8.3 the reallocation of the warehouse will on average result in less travel distance for both the pallet area and the shelving area. In this section the shelving area and the pallet area are discussed separately, starting with the pallet area.

9.3.1 Pallet area

For the reallocation of the parts in the pallet area, a combination of class-based storage and cube-per-order index (COI) is created. The pallet area is divided into three different areas and within these areas an COI strategy is computed. Dependent on the picks per I/O point, parts are divided over the areas. Within the areas, parts are located dependent on the number of picks per part. This technique is explained and visualized in Section 7.3.1.

The new storage strategy is tested in Section 8.3.1 and the average travel distance decreases with 34.8 %. Besides that, the usage of the reach truck is minimized with this new method. This again improves the efficiency.

With the information from Figure 7-10 and Table 7-8 the new allocation can be performed. In Table 7-8 the location of the pallets is depicted. With this information the first three layers of the pallet area are reallocated.

This reallocation is done with the following steps:

Step 1:
Empty the first three layers in the C aisle.
Step 2:
Fill the C aisle as depicted in Section 7.3.1.
Step 3:
Locate the rest of the pallets in the empty locations.
Step 4:
Repeat the first three steps for the A and B aisles.
Step 5:
Swap pallets such that overstock of the same parts are located close to that part.

With this redesign the overall efficiency within the warehouse will increase, but to maintain this efficiency it is important to keep updating this new policy.

This new policy must be updated once a year. New data should be gathered from the ERP system. This new list of data needs to be located and ranked regarding their popularity and picks per I/O point (as shown in Section 7.3.1). With this data a new allocation can be created and changes ought to be adjusted, to keep the storing of parts as efficient as possible.

9.3.2 Shelving area

For the reallocation of the parts in the shelving area, a combination of class-based storage and cube-per-order index is computed. The shelving area is divided into three different areas and within these areas an COI strategy is used. Dependent upon the picks per I/O point, parts are divided over the areas. Within the areas parts are located dependent on the number of picks per part. Each shelf can on average contain 24 bins and these bins are located within a shelf dependent on the bin size. This technique is explained and visualized in Section 7.3.2.

The new storage strategy is tested in Section 8.3.2 and the average travel distance decreases with 24.9 %. Beside this travel distance reduction the use of the ladder is minimized with this new method, thus improving efficiency.

With the information from Figure 7-12 and Table 7-10 the new allocation can be performed. In Table 7-10 it is shown which pallet is located at which location. The locations are depicted in Figure 7-12.

In Figure 9-3 the new allocation is depicted. The shelving area is divided into three zones and in these zones the shelves are numbered. The first 24 bins of one zone are located in the first shelf, etcetera. A more extensive explanation of the heatmap itself is done in Section 8.3.2.

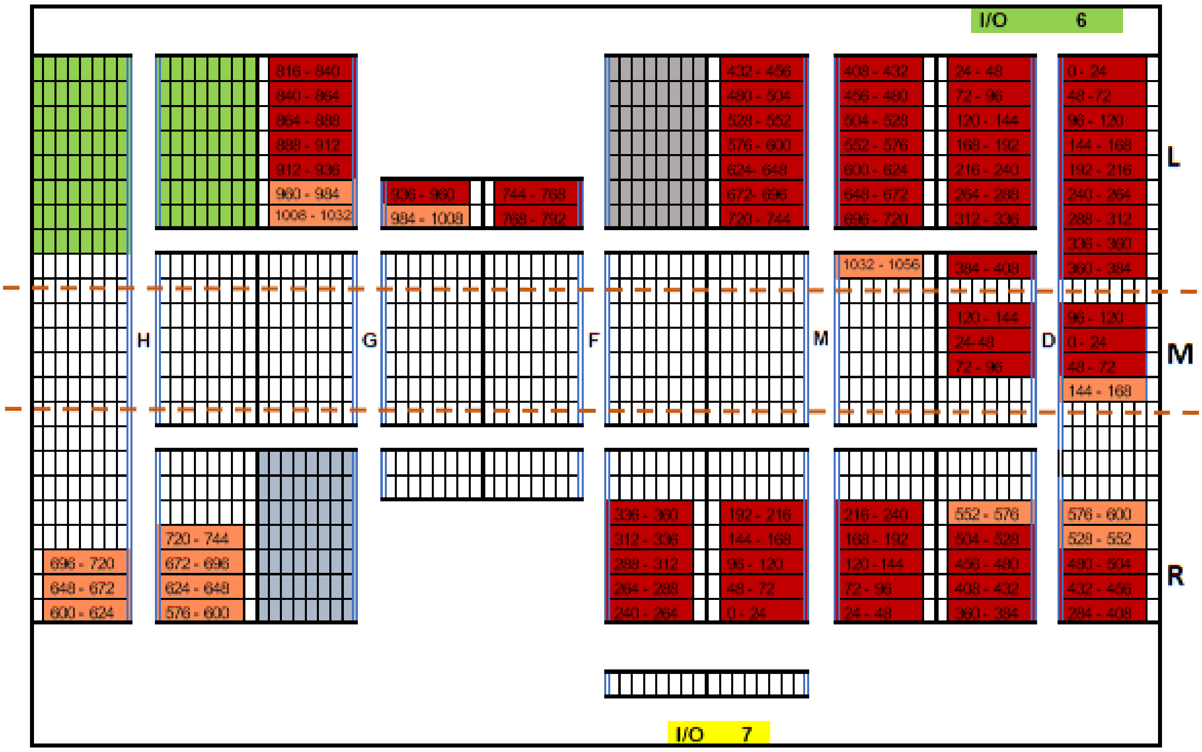

FIGURE 9-3, HEATMAP NEW ALLOCATION SHELVING AREA

This reallocation is done with the following steps:

Step 1:

Empty the first shelf in the zone L.

Step 2:

Fill the first shelf in the zone L as depicted in Section 7.3.2.

Step 3:

Repeat the first two steps for all the shelf in zone L.

Step 4:

Locate the bins that do not have a location yet.

Step 5:

Repeat step 1 - 4 for zones M and R.

With this redesign the overall efficiency within the warehouse will increase, but to maintain this efficiency it is important to keep updating this new policy.

This new policy must be updated once a year. New data must be gathered from the ERP system. This new list of data needs to be located and ranked regarding their popularity and picks per I/O point (as described in Section 7.3.2). With this new data a new allocation can be created and changes need to be adjusted to keep the storing of parts as efficient as possible.

9.4 Order picking process

Three components in the order picking process are discussed in Section 7.4. Within this section these three components are discussed according to the implementation and maintenance. This section starts with the picking zones, followed by the ladders and the last part describes the equipment usage.

9.4.1 Picking zones

The method of working is unsuitable for zone picking. Thus when implementing zone picking the method of working must be adjusted. Different steps are needed to make the implementation of zone picking a success.

The first step is dividing the warehouse in picking zones. This is already done in Section 8.4 where the warehouse is divided into two zones:

- The shelving area and the first three layers of the pallet area → these parts are picked by hand.
- The other layers of the pallet area → these parts are picked by a reach truck.

The second step is dividing the orders. When an order comes in the order has to be divided into two different zones. In that way the operator picks the parts in his/her zone.

There is only one reach truck at Trioliet, so this reach truck has to pick the parts for both sides of the warehouse.

An information flow from the department to the reach truck is required, to ensure that the driver can stay on the reach truck and get the information he/she needs to pick the parts. The information that he/she needs is depicted in Table 9-1. With his information the operator can stay on the reach truck and keep working and thereby efficiency is improved.

Information
Part number
Location
Amount needed
Which I/O point
Urgent or not

TABLE 9-1, INFORMATION FOR REACH TRUCK DRIVER

The work for the other operators can stay the same, the only difference is that he/she does not have to wait and search for the reach truck. The parts from the 'reach truck area' are picked by another operator and located in the 'drop zone'. When the order is complete the operator can pick the parts from the 'drop zone' and pack the whole order.

At a later stage, when this zoning is a success, the zones can be extended to three zones as explained in Section 7.4. Especially when other equipment is introduced for the order picking in the pallet area, this third zone can increase the efficiency.

When the new ERP system is implemented and barcode scanning is introduced this zoning can become even more efficient. The automatization can make the communication easier and faster, whereas new orders can be sent directly to the barcode scanner.

9.4.2 Ladders in shelving area

In Section 7.4 the problem of the ladders in the shelving area is introduced. The solution for this problem is to not use the highest layer for bins, but only for overstock. With this adjustment the usage of the ladders can be minimized.

The ladders that remain are located outside the shelving area and operators can pick the ladder when needed (to refill a bin or locate new overstock). With this method the ladders are not standing in the way that often.

When in practice this is not working, another option is introduced in Section 7.4 namely the track ladder. The cart can pass this ladder and therefore this problem can easily be solved with this sort of ladder.

9.4.3 Equipment used in pallet area

A cart is used to pick the parts in the pallet area. In Section 8.4 it is explained that the introduction of a picking truck can improve the efficiency.

To have maximum use of this picking truck the zoning has to expanded to three. Whereby an operator is responsible for the pallet area and picks all the parts from the first three layers (or when a picking truck with rising platform is used, four or five layers).

More research is needed to give an advice about which picking truck to choose.

9.5 Investigate other option: Automation

The implementation of VLM's or vertical carousels can be realized in a lot of ways. One of the suitable options is discussed within this section, at this moment this options seems the best option for Trioliet.

The advice that is given in Section 7.5 is depicted in Figure 9-4. All the shelves are replaced for six VLM's. One VLM can contain around 2,000 parts, so six VLM's contain approximately 12,000 parts.

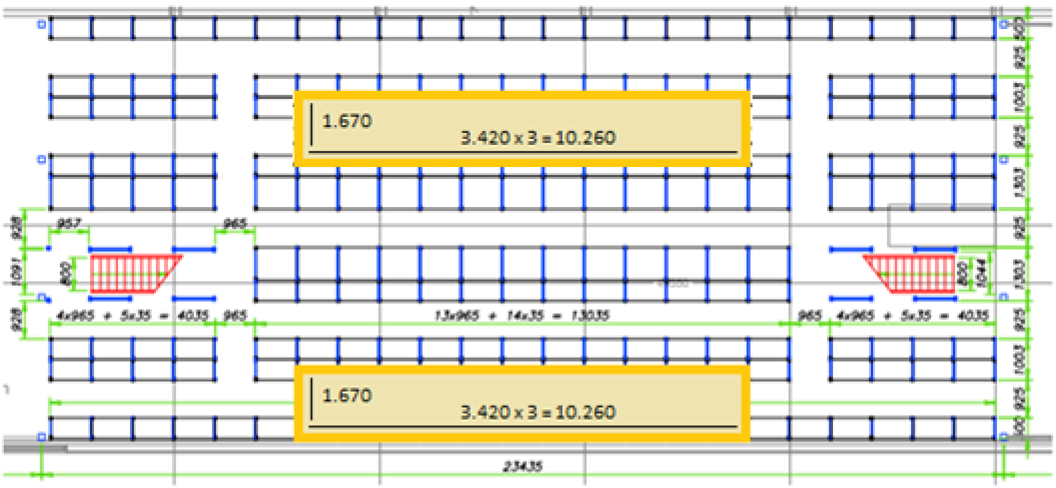

FIGURE 9-4, LOCATION NEW STORAGE SYSTEM

One operator is able to pick in three VLM's. In the middle there is a transport belt where bins can be transported to both sides of the warehouse as depicted in Figure 9-5.

FIGURE 9-5, NEW STORAGE SYSTEM

The steps of this process are:

Step 1:

The bin arrives at the transport belt.

Step 2:

*The operator picks the part out of his/her shelves.**

Step 3:

The bin is transported to the right I/O point.

Step 4:

When the bin of both sides (shelves at the left and right side of the transport belt) are at the I/O point the bins are combined.

Step 5:

The bin is combined with parts of pallet area and the box/pallet is closed and ready for transport.

* When the operator picks the parts out of the VLM, he/she puts on the red button and a new layer is transported to the picking table/layer. In the mean time the operator picks a part from another VLM.

The introduction of VLM's requires a new working method. One operator is responsible for his/her VLM's, both the refill as the order picking. With the introduction of the VLM's zone picking instead of picking by order is inevitable.

The VLM's can be combined with a label printer. In that way when a part is picked a label is automatically printed. When the operator pushes the red button, the label is printed and the operator can put the label on the ziplock bag.

9.6 Summary implementation plan

In this chapter the implementation and maintenance plan for Trioliet is outlined. The outcome for the different sections is summarized here.

Receiving process
A new desired situation is proposed for the receiving area. Three extra pallet racks are added:

- Location X   Temporary storage for production orders.
- Location Y   Temporary storage for incoming goods.
- Location Z   Extra storage space in the warehouse.

With the introduction of these new storage racks less ground space is occupied on average. Furthermore, the incoming goods area is better organized and moreover the searching time decreases.

For maintenance it is important that the pallet racks are strictly used for what they are built for.

Set production
A new allocation of parts within a set is created. This new allocation results in 56.9% travel distance reduction and a decrease in searching time.

A heuristic with as starting point the OOS strategy is used to allocate the parts. The decision has been made to locate the parts in the first nine layers of the G aisle, such that all parts are located close to each other.

To maintain this near optimal allocation it is important to update this heuristic once a year.

Storage strategy
A new desired situation is proposed for the storage of parts. A combination of class-based storage and COI is designed to minimize the total travel time for both I/O points. This is done for the pallet area and the shelving area.

Pallet area

This new allocation results in a travel distance reduction of 34.8% and minimizes the usage of the reach truck. An action plan is created to implement this new storage policy.

Shelving area

This new allocation results in a travel distance reduction of 24.9 % and minimizes the use of the ladders. An action plan is created to implement this new storage policy.

Order picking process
For the order picking process a small implementation plan regarding the introduction of picking zones is discussed. At first the warehouse is divided into two picking zones:

- The shelving area and the first three layers of the pallet area → these parts are picked by hand.
- The other layers of the pallet area → these parts are picked by a reach truck.

This will make the picking process more efficient by minimizing the wait and searching time for the reach truck.

Furthermore, the ladders in the shelving area are discussed. This problem is hopefully solved by not allocating bins to the highest layer. When this is not the solution, another kind of ladder is introduced.

Investigate other option: Automation
An implementation plan for a new storage system for small parts that seem interesting for Trioliet is described in this section. An implementation plan for six VLM's with a transport belt in the middle is worked out. Zone picking is advised when this new goods-to-person storage system is implemented. One operator is responsible for his/her VLM's, both the picking of parts and the refill.

Chapter 10 - Conclusions and recommendations

The last chapter of this report describes the conclusions and recommendations of this research. The objective of this research is to improve the efficiency of the warehouse of Trioliet. This research had to give insights in the current inefficiencies and come up with solutions. The objective was formulated as:" How to get the flow of goods more efficient within the warehouse by improving the storage of parts and the picking of orders? Furthermore, what are the savings of these improvements and how can these be implemented?". This research exposed a couple of inefficiencies with regards to the current situation. These inefficiencies are observed and their performance is measured and calculated. For these inefficiencies, different solutions are designed and tested. For the solutions that improve the process an implementation plan is created. In this chapter the conclusions are withdrawn from this research and recommendations are given.

This chapter starts with the conclusion for the receiving area in Section 10.1. Besides that, in Section 10.2 the conclusion for the sets is explained. Furthermore, Section 10.3 described the conclusion about the new storage allocation. In Section 10.4 the conclusion for a new picking process is explained. Section 10.5 concerns an automatization possibility. In the last section of this chapter some recommendations that are not mentioned in the report are discussed.

10.1 Receiving process

The activities in the receiving process are observed and analyzed. Two inefficiencies where exposed:

- Unnecessary search time, because documents are taken of the pallet. The second operator has to pick the documents and search for the box or pallet.
- Not enough temporary storage space. Boxes and pallets are located wherever is space, which creates chaos in the receiving area.

To overcome these problems three new pallet racks are introduced, as depicted in Figure 10-1.

- Location X — Temporary storage for production orders.
- Location Y — Temporary storage for incoming goods.
- Location Z — Extra storage space in the warehouse.

To maximize the benefits of these new racks it is important to extend those induction lines, so that the reach truck can easily pick in those pallet racks.

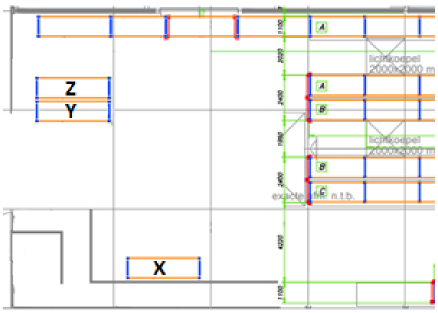

FIGURE 10-1, NEW PALLET RACKS

With the introduction of these new pallet racks the inefficiencies are solved.

- The incoming goods can get a temporary storage location and thereby the searching time is decreased.
- On average less space is occupied, because there are more vertical storage possibilities.

No quantified data is created, but after interviews with those involved and observing the process it can be concluded that the pallet racks will improve the efficiency at the incoming goods department.

It can also be concluded that the new storage racks will result in extra storage space, less searching time and decrease of total ground space used.

Recommendations

It is important that the new pallet racks are strictly used for what they are built for.

- Location X is used for temporary storage for production orders.
- Location Y is used for temporary storage for incoming goods.

When the racks are used for other purposes the same problems will return in the future.

10.2 Set production

Observations, clocked data and analyzing the created heatmap expose some inefficiencies during the set production:

- Long travel distances, because the parts within a set are located all over warehouse.
- All the different components must be packed in separate bags which takes a lot of time.
- Each ziplock bag needs a handwritten product number which requires a lot of time.
- There is no bulk production because of insufficient stock.

For these inefficiencies different solutions are proposed and discussed. These solutions are divided in 'travel time' and 'manually set production'. Furthermore, the set Trioform knife is handled separately.

Travel time

In the old situation the parts are located throughout the entire warehouse, resulting in unnecessary extra travel time. The average travel distance to pick a set is 65 meters in the old situation.

A new storage strategy with as starting point the order-oriented slotting strategy is created. With help of this heuristic a new allocation is designed. The first nine shelves of the G aisle are emptied and the parts are relocated.

After this reallocation of the set parts, the average travel distance to pick a set is 28 meters. This is a reduction of 56.9%.

Manual set production

A problem that occurred during the observation is that the packing process was done fully manual. Especially writing the product number on the ziplock bag and packing the parts in separated bags are time-consuming processes.

Possible solutions for these problems are outsourcing, purchase pre-packed sets or automatization. For the most picked set (Trioform knife) the outsourcing option and purchase pre-packed sets are analyzed as example. This is done because the cost and benefits are different per set. The solution of this is discussed in the third part of this section. First automatization options are discussed.

After discussion with different automation suppliers it can be concluded that fully automatization is not an option for Trioliet. The batches are too small and the parts are to diverse, which results in long changeover times. Options that are interesting for Trioliet are a label printer and/or a packing machine.

Label printer: A label printer makes the 'writing of product number' less time-consuming and gives the sets a more professional look. Parts in a set are often packed separately and this label printer can make it better organized.

At first the labels are printed manually, but with the introduction of the new ERP system and the scanners this can be done automatically. Automating the printing makes the process more efficient and reliable (when all stickers are used the set is complete).

Packing machine: A packing machine automates the whole packaging process and can also automate the stickering process. This machine can make the packaging process more efficient and also gives the sets a more professional look (sealed bags and a clear printed barcode).

Test set: Trioform knife

For the Trioform knife set the costs of the different options are analyzed. The best option is to buy pre-packed sets of this set. A test batch of this pre-packed set is purchased and Trioliet is currently testing this.

How	Per set
Employee Trioliet	€ 0.11
Employee Larcom	€ 0.06
Outsource to Larcom	€ 0.09
Pre-packed purchase	€ 0.05

TABLE 10-1, COST FOR TRIOFORM KNIFE SET

Recommendations

There are two recommendations when this new allocation is implemented:

- When a new set is introduced, the underlying parts need to be located in one of these nine shelves. If these nine shelves are fully occupied a tenth shelf has to be introduced.
- The heuristic must be updated once a year. New data per set should be gathered and the heuristic needs to run. This updated heuristic needs to be implemented to keep the allocation of parts near optimal.

When after testing the pre-packed 'Trioform knife' set is a success, Trioliet should start purchasing this set as a pre-packed set and test this pre-packed purchasing for other sets.

10.3 Storing strategy

Observations, clocked data and analyzing the created heatmaps expose two inefficiencies during the picking process.

- Parts are located throughout the entire warehouse, with long travel distances as a consequence.
- Parts are located at high layers with long picking times as a consequence.

A new storage strategy is created to reallocate the parts. Trioliet makes use of two I/O points, so a combination of class-based and cube-per-order index (COI) is used.

Class-based: First the warehouse is divided in three different zones.

- 100-75% picks are done at spare parts	I/O point 7	Right
- 100-75% picks are done at incoming goods	I/O point 6	Left
- Less than 75% are done at one location.		Middle

COI: In each zone parts are located with the COI approach.

The cube-per-order index allocate the parts to a storage location according to their popularity. Parts that are often picked are located close to the floor and close to the I/O point.

This is done for the pallet area and the shelving area:

Pallet area: With this new storage strategy the travel distance from both I/O points decreases and the usage of reach truck is minimized.

- For I/O point 7 the travel distance reduces from 40.8 meters to 29.4 meters, which is a reduction of 27.9%
- For I/O point 6 the travel distance reduces from 45.7 meters to 26.7 meters, which is a reduction of 41.6%

Shelving area: With this new storage strategy the travel distance from both I/O points decrease and the use of ladder is minimized.

- For I/O point 7 the travel distance reduces from 18.4 meters to 15.3 meters, which is a reduction of 16.8%
- For I/O point 6 the travel distance reduces from 17.6 meters to 11.8 meters, which is a reduction of 32.9%

Recommendations

This new policy must be updated once a year. New data should be gathered from the ERP system. This new list of data needs to be located and ranked regarding their popularity and picks per I/O point. With this new data a new allocation can be created and changes need to be adjusted, to keep the storing of parts as efficient as possible.

When Trioliet chooses to not directly redesign the whole warehouse they should translocate those parts that cannot picked by hand to higher locations, so that parts that can picked by hand can be located at lower layers.

10.4 Order picking process

The activities of the order picking process are observed and analyzed. Five inefficiencies are exposed here:

- Parts are picked in small amounts, because parts are heavy and difficult to handle.
- Long travel times, because part picking with reach truck can take a lot of time.
- Long travel times, the operator has to travel through the whole warehouse.
- Ladders that are used in shelving area stand in the way during picking process.
- Equipment used makes the picking process more time-consuming.

These inefficiencies are discussed on the basis of three different sections.

Picking zones
One of the problems that occur during the picking process is that an operator has to walk through the whole warehouse to pick all the parts needed in the order. Especially picking parts that are located in the high layers of the pallet area, because the reach truck is needed to pick those parts.

There is one reach truck in the warehouse that is used at both I/O points, with long travel times, searching time and start up time as a consequence. Besides that, the reach truck is often occupied. This creates waiting time. As a consequence, part picking can take an enormous amount of time.

After observing and analyzing the process a new picking policy with two picking zones could make the process more efficient. These two zones are:

- The shelving area and first three layers of pallet area → these parts are picked by hand.
- The other layers of the pallet area → these parts are picked by a reach truck.

With this division in zones the same employee can drive on the reach truck and pick the parts needed for both I/O points. This reduces the total picking time drastically.

When barcode scanning is introduced, this zoning can become even more efficient because the communication becomes easier and faster. Thereby, new orders can be sent directly to the barcode scanner.

Ladders in shelving area
Another problem that occurs during the picking process is that the ladders in the shelving area are standing in the way and a cart cannot pass the ladder. After interviewing the operators and observing the process it can be concluded that the ladders are only used for picks at the highest layer.

The simplest solution, that is already implemented in the new allocation, is not using the highest layer for bins, but just for overstock. As a consequence the ladder is used a lot less and can be located somewhere outside the shelving area.

When this solution is not working, another solution is the introduction of a track ladder. This ladder is attached to a rod in the shelving area, when the ladder is folded the cart can pass the ladder.

Equipment used in pallet area
At Trioliet they are using a cart to pick parts both in the shelving area and the pallet area. The operator has to walk in the warehouse which can take an enormous amount of time, especially in the pallet area. Besides that, large parts are difficult to transport with the cart, which can result in part picking instead of order picking.

The order picking process can become more efficient by introducing a ride-on picking truck. The operator can stand on the truck and thereby travel time decreases (a ride-on carrier is 40 % faster if the distance is about 25 meters (Unicarriers, 2017)). Furthermore, the picking truck can transport pallets or other storage materials and thus increase storage space and storage options.

Which pallet truck is the best choice is not decided yet. There are pallet trucks with rising forks and/or rising platform, single or double forks, so a lot of different options.

Recommendation

When the zoning as described is a success this can be expanded to three zones as described in Section 9.4. The parts in this zone can be picked by a newly introduced picking truck.

10.5 Investigate other options: Automation

The research for other storage options started because there are four inefficiencies in the storage system used at this moment.

- A lot of ground space is needed to locate all the parts.
- There is a lot of travel time between the different parts.
- Parts are located on high layers, so a ladder is needed.
- Parts are located on a low not ergonomic working height.

A solution for these problems is the introduction of a goods-to-person storage system. With the help of external companies is concluded that two options are interested for Trioliet, the VLM and the vertical carousel.

An option for the lay-out with six VLM's is depicted in Figure 10-2. An VLM can contain around 2000 parts, so six VLM's can contain around 12,000 parts. One operator has control over three storing systems. In the middle is a transport belt, bins can be transported to both sides of the warehouse (both I/O points).

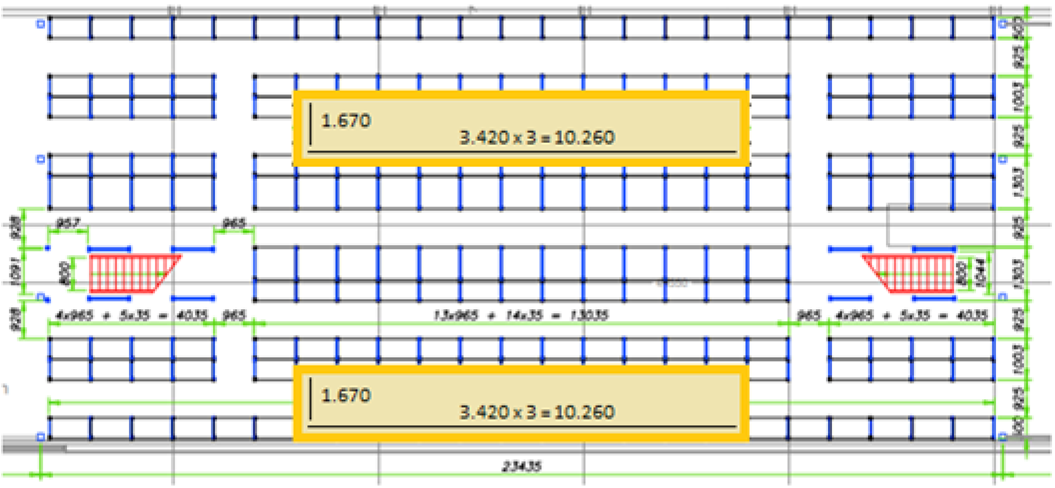

FIGURE 10-2, GOODS-TO-PERSON STORAGE SYSTEM IMPLEMENTATION

With the introduction of this new storage system the inefficiencies are solved.

- Less ground space is needed, because a high utilization level and use of vertical storage space.
- Travel time is reduces, because of the goods-to-person principle.
- Ergonomic working height, the tray is delivered at an individually set working height.

Recommendations

Despite that an lay-out for the implementation is given, further research is needed before implementing a goods-to-person storage system. In this research is proven that a goods-to-person storage system is, when implemented correctly, an efficiency improving investment for Trioliet. However there are numerous different options that should take into account to find the most efficient implementation for Trioliet.

The recommendation from this research is to choose a company that produce goods-to-person storage systems and create, together with that company, a customized implementation plan. This new storage system is a large investment, but when done correct this will make the picking process more efficient and the investments will be repaid.

10.6 Recommendations

In this section some advices for Trioliet, that are not mentioned in the report yet, are discussed.

It is advisable for Trioliet to put a lot of effort in the new ERP system. The current ERP system is outdated and Trioliet is currently implementing a new ERP system. A lot of manual work is done with the old ERP system while an ERP system must simplify and support activities. With this new ERP system lots of manual activities can be eliminated or reduced. It is also advisable for Trioliet to combine this ERP system with new technologies like barcode scanning. This can make the communication simpler and can reduce the use of papers. New orders can be sent to the scanner in real time, which makes the picking process more efficient.

Another advice for Trioliet is to close the warehouse for production employees. Currently, production employees can walk in the warehouse and pick parts. this results in stock discrepancy and complexities. Production employees must report when they pick a part, but in practice this is almost never done. They are also not familiar with the reorder rules, which can result in out of stocks. This can be solved by closing the warehouse and letting production employees order the parts they need at the desk of the warehouse.

The warehouse is responsible to resupply production and this costs the operators a lot of time. An advice for Trioliet is to research this process and analyze if there are efficiency improvements possible. The two-bin system is a well-known system to resupply production, but this a time-consuming process for the operators in the warehouse. Besides that, there are some incoming goods that cost a lot of time to locate in the production area. For example the air hoses, these hoses are delivered in a box and an operator has to check each hose and bring it to its designated storage location.

A problem during the set production is insufficient stock. When Trioliet wants to produce sets in advance it is important that the stock of the underlying parts is sufficient. In practice this stock is not always sufficient, with as a consequence that sets are not produced in large batches. As a result, sets are produced in small batches which is inefficient and sometimes sets are even out of stock. The advice for Trioliet is to purchase these underlying parts in such a way that sets can be produced in bulk, and thereby increase the efficiency of the set production.

In the shelving area are some products that consist out of two different parts. The problem with these products is that the operators are not aware that the product consist out of two parts and as a consequent he/she picks only one of the two parts. A solution for this problem is a bin with a partition wall. Both parts can be stored in the same bin, so that the operator can see that the product consist out of two parts and picks both parts.

FIGURE 10-3, ADVISED BIN (SETAM, 2018)

At this moment Trioliet uses headsets with a small range. When an employee is in the warehouse or in production the headset has no range. The consequence of that is that the employees are not reachable when they are in the warehouse or in production, with as result that communication problems arise and customers for example have to call back. A simple solution for this problem is a headset with a larger range.

10.7 Roadmap

A roadmap for the different inefficiencies is created and depicted in Figure 10-4. These inefficiencies are discussed in the following paragraphs.

<table>
<tr><th>Inefficiency</th><th>Short-term</th><th>Middle-term</th><th>Long-term</th></tr>
<tr><td>The receiving process</td><td>Built new storage racks →</td><td>Extend induction lines</td><td></td></tr>
<tr><td>Set production</td><td>Relocate set parts
Test case: Trioform knife</td><td>Label printer →</td><td>Packing machine</td></tr>
<tr><td>Storage of parts</td><td colspan="2">Relocate pallet area
Relocate shelving area</td><td></td></tr>
<tr><td>Order picking</td><td>Two picking zones →
Relocate parts at highest layer →</td><td>Picking truck →
Track ladder</td><td>Three picking zones</td></tr>
<tr><td>Automation</td><td>Choose a company →</td><td>Create a lay-out →</td><td>Implementation</td></tr>
</table>

FIGURE 10-4, ROADMAP

The receiving process

The building of the new racks has to start as soon as possible. These racks improve the efficiency significantly and the accompanying costs are relatively low. To maximize the benefits, the induction lines should be extended. However, this is less important and can be done at a later stage.

Set production

The relocation of the set parts results in a significant efficiency improvement and requires a relatively short time. Thus this relocation can be done within the short-term.

All information that is required for the test case is known at Trioliet and they can just order the test case and start using the test boxes. This process is possible to be accomplished within the short-term. After the test, Trioliet has to choose if they continue with this new way of ordering sets and can start test cases for other sets, when this first test is a successful one.

First, the new ERP-system has to run completely. Furthermore, for this new ERP system, different options to print the labels have to be investigated. At a later stage, a packing machine can replace the whole packing and labeling process.

Storage of parts

Relocating the parts is a time-consuming process. Trioliet has to start with this in a period when they are not overloaded with activities, because of that it is located in between the short and middle-term time horizon.

Order picking

Trioliet can directly start with dividing the warehouse into two picking zones. Later on, a picking truck for the pallet area would be interesting. When this picking truck is implemented, the picking zones can be extended to three.

Relocating the parts at higher layers solves the problems occurring with the ladders. When this is not working in practice, the implementation of a track ladder is a second option.

Automation

Implementing a goods-to-person storage system is a costly and time-consuming process. It is important to choose the right company and system here. Trioliet should continue with this project and do further research to find out which goods-to-person storage system is the best option for them.

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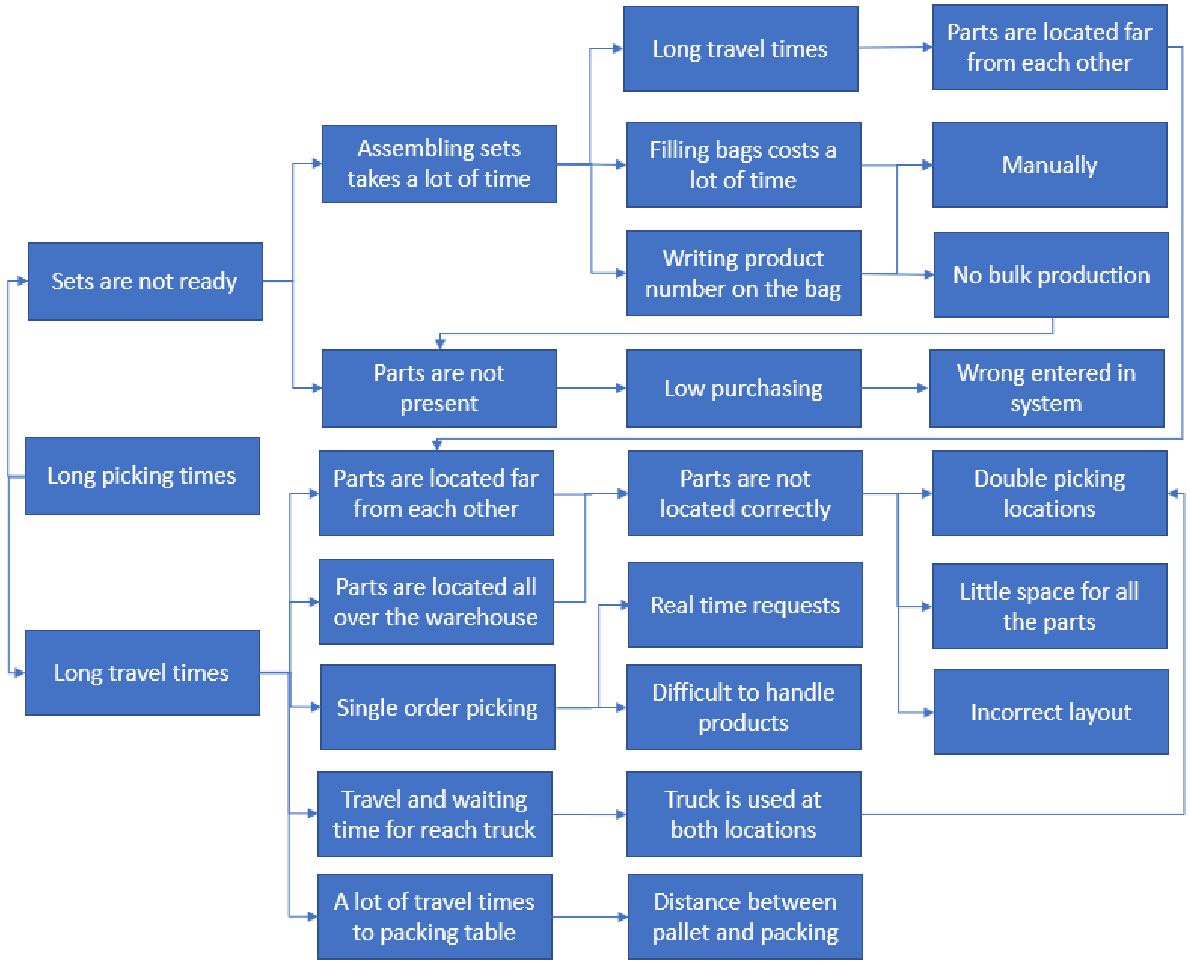
Appendix A

Problem mind map. Starting with long picking times.



Appendix B

This are the sets that are clocked.

sets	amount	Time in minutes	per set	Order rules
0500576	40	20	0.50	2
0500192	10	15	1.50	5
05949	5	15	3.00	3
0500451	10	30	3.00	6
05948	15	20	1.33	3
0500328	5	80	16.00	21
01003	5	50	10.00	16
0500446	50	80	1.60	6
0500452	40	80	2.00	6
050004	10	10	1.00	4
05054	11	30	2.73	3
0500347	50	16	0.32	3
05309	40	20	0.50	4
05476	11	25	2.27	2
05955	10	8	0.80	2
05026	10	10	1.00	3
05949	25	15	0.60	3
0500542	20	190	9.50	12
05948	50	25	0.50	3
05737	50	10	0.20	3
05464	5	17	3.40	5
0500328	30	480	16.00	21
05001	10.0	15.0	1.5	5.0
05115	10	30	3.00	6
0500169	10	30	3.00	6
050294	200	135	0.68	2
05522	50	180	3.60	8
	29.0	**60.6**	**3.3**	**6.0**

Appendix C

An example from the output of the tool created by Bartholdi, Tang and Cubbillos (2018):

1004: START ->0H4100 ->0F5100 ->0F4900 ->0M4200 ->0M4100 ->0M3700 ->0M3400 ->0M2900 ->0M1000 ->0M0500 ->0D0400 ->0D0600 ->0C3600 ->0C3400 ->0C3200 ->END
The length of the path is: 98.0
0500328: START ->0H4100 ->0F5100 ->0F4900 ->0M4200 ->0M4100 ->0M3700 ->0M3400 ->0M2900 ->0M1000 ->0M0500 ->0D0400 ->0D0600 ->0C3600 ->0C3400 ->0C3200 ->END
The length of the path is: 98.0
0500329: START ->0H4100 ->0F5100 ->0F4900 ->0M4200 ->0M4100 ->0M3700 ->0M3400 ->0M2900 ->0M1000 ->0M0500 ->0D0400 ->0D0600 ->0C3600 ->0C3400 ->0C3200 ->END
The length of the path is: 98.0
0500334: START ->0F5100 ->0F4900 ->0M4200 ->0M4100 ->0M3900 ->0M2900 ->0M0100 ->0C1600 ->0C3200 ->0C3600 ->END
The length of the path is: 80.0
0500336: START ->0F5100 ->0F4900 ->0M4200 ->0M4100 ->0M3900 ->0M2900 ->0M0100 ->0C1600 ->0C3200 ->0C3600 ->END
The length of the path is: 80.0
0500341: START ->0F5100 ->0F4900 ->0M4200 ->0M4100 ->0M3900 ->0M3400 ->0M2900 ->0M0300 ->0M0100 ->0C1600 ->0C3600 ->0D4500 ->END
The length of the path is: 82.0
05000346: START ->0F4900 ->0C3200 ->END
The length of the path is: 36.0
0500447: START ->0F4900 ->0M0300 ->0D4500 ->END
The length of the path is: 68.0
0500448: START ->0F4900 ->0C3200 ->END
The length of the path is: 36.0
0500450: START ->0F4900 ->0C3200 ->END
The length of the path is: 36.0
0500451: START ->0F4900 ->0C3200 ->END
The length of the path is: 36.0
0500452: START ->0F4900 ->0C3200 ->END
The length of the path is: 36.0
01002: START ->0H4100 ->0F4900 ->0M4100 ->0M3600 ->0M2900 ->0M1000 ->0M0500 ->0D0400 ->0D0600 ->0C3600 ->0C3400 ->END
The length of the path is: 90.0
01003: START ->0F5100 ->0F4900 ->0M0100 ->0M2900 ->0M3600 ->0M3500 ->0M4100 ->0C3600 ->END
The length of the path is: 80.0
05948: START ->0F4100 ->0M3800 ->END
The length of the path is: 32.0
05949: START ->0F4100 ->0M3700 ->END
The length of the path is: 32.0
0500192: START ->1D2400 ->1F1300 ->0G3200 ->0F2600 ->0M1600 ->END
The length of the path is: 58.0
0500576: START ->0F0700 ->0F2200 ->END
The length of the path is: 64.0

Appendix D

Clocked orders from spare parts I/O point.

Order Nr.	Order lines	Time Minutes	Seconds	Second per line	Weight
425231	3	8	480	160.00	7
425214	4	45	2700	675.00	80
425229	7	8	480	68.57	13
425266	12	25	1500	125.00	26
425278	13	25	1500	115.38	17
425314	15	83	4980	332.00	115
426945	1	1	60	60.00	1
426944	4	5	300	75.00	3
425066	11	70	4200	381.82	160
425076	13	18	1080	83.08	22
424920	19	140	8400	442.11	65
425000	9	24	1440	160.00	42
425001	21	30	1800	85.71	
424987	3	15	900	300.00	6
424959	5	25	1500	300.00	20
424950	1	5	300	300.00	1
424956	6	40	2400	400.00	80
426947	9	10	600	66.67	28
426949	2	7	420	210.00	41
426950	1	4	240	240.00	20
426948	2	18	1080	540.00	144
426956	1	2	120	120.00	3
427193	5	9	540	108.00	25
427197	1	6	360	360.00	2
427191	9	9	540	60.00	6
427198	1	3	180	180.00	1
427192	1	4	240	240.00	23
427202	1	5	300	300.00	12
427201	3	9	540	180.00	4
427204	2	9	540	270.00	23
427364	15	25	1500	100.00	10
427326	11	23	1380	125.45	33
427413	13	80	4800	369.23	35
427439	2	5.5	330	165.00	16
427393	8	31	1860	232.50	45
427414	2	2.5	150	75.00	1
427410	3	4.3	258	86.00	9
427390	11	13	780	70.91	14
427388	1	6	360	360.00	5
427392	9	16	960	106.67	21
427369	5	4	240	48.00	7
427365	1	2	120	120.00	4
427363	1	2.5	150	150.00	1
427343	1	3	180	180.00	15
427325	2	4	240	120.00	3
427342	1	3	180	180.00	3
427341	1	11	660	660.00	12
427648	7	13	780	111.43	17
427632	4	13	780	195.00	41

427605	2	10	600	300.00	18
427624	4	12	720	180.00	23
427621	1	2	120	120.00	11
427627	4	7	420	105.00	2
427628	1	3	180	180.00	3
427609	1	10	600	600.00	1
427541	13	50	3000	230.77	138
427602	3	2	120	40.00	2
427601	2	1	60	30.00	1
427593	1	1	60	60.00	2
427595	1	1.5	90	90.00	1
427592	1	1	60	60.00	2
427584	1	2	120	120.00	9
427555	6	13	780	130.00	34
427545	3	16	960	320.00	23
427540	1	33	1980	1980.00	54
427528	11	35	2100	190.91	16
Average	**5**	**17**	**1021**	**205**	**25**

Appendix E

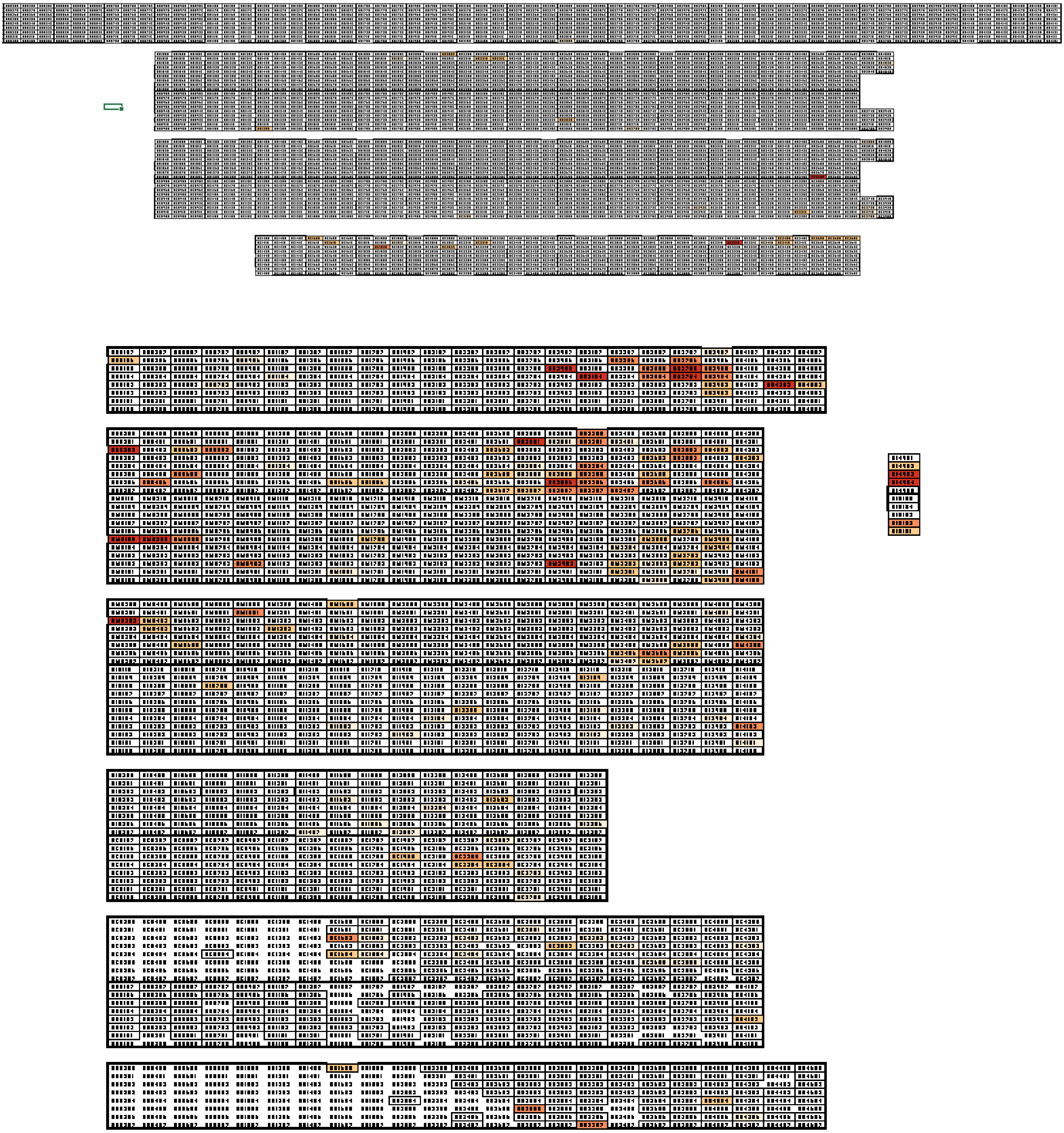
Clocked orders from the incoming goods I/O point.

Order nr.	Order rules	Time in Minutes	Seconds	Seconds per rule
129196	46	17	1020	22.17
129614	40	13	780	19.50
129506	45	18	1080	24.00
129127	62	50	3000	48.39
128907	40	33	1980	49.50
129251	41	13	660	16.10
129516	43	8	480	11.16
128908	40	47	2820	70.50
129596	35	9	540	15.43
129103	37	8.75	525	14.19
129104	37	8.75	525	14.19
129105	37	8.75	525	14.19
129106	37	8.75	525	14.19
129107	37	8.75	525	14.19
129108	37	8.75	525	14.19
128917	37	8.75	525	14.19
129204	49	19	1140	23.27
128917	46	12.5	750	16.30
129222	44	30	1650	37.50
129367	36	9	540	15.00
128341	45	11	660	14.67
129315	47	13	780	16.60
129224	50	11	660	13.20
129088	43	28	1680	39.07
Average	**42.125**	**17.79375**	**995.625**	**25.99**

Appendix F

Heatmap for all the sets together, with the map legend.

<=10,	
>10,	
>50,	
>200,	
>500,	



Appendix G

The heuristic created for the allocation of sets.

Indices

i	= 1,2,….,I	SKU	205 different parts
p	=1,2,….,P	Location	10 shelves are used
k	=1,2,….,K	Order	73 order set

Parameters

O_k	Order set	all SKUs in order k
D_{p1p2}	Distance from p1 to p2	distance from shelf to shelf
Mult(k) = multiplicity of order k		number of picks of order set k

Variables

X_{ip} = 1 if SKU i is located at location p
0 if not
If i is located at shelf p

Zkp_1p_2 = 1 if order k is located at location p_1 and p_2
= 0 if not

ILP

$$Min \sum_{k=1}^{k} mult(k) * \sum_{p_1}^{p} \sum_{p_2}^{p} d * p_1 * p_2 * Zkp_1p_2 + \sum_{k=1}^{k} mult(k) * \sum_{i=1}^{I} \sum_{p=1}^{P} d_{op} * x_{ip}$$

$\sum_{p=1}^{p} x_{ip} = 1$	$\forall$ I	(1)
$\sum_{i=1}^{I} x_{ip} \leq S$	$\forall$ p	(2)
$x_{i1p2} + x_{i2p2} - 1 \leq Zkp_1p_2$`	$\forall\ p_1p_2\quad \forall\ k\quad \forall\ i_1i_2 \leftarrow O_k$	(3)
$x_{ip\ ,Zkp_1p_2}$ $\{0,1\}$	$\forall$ i,p,k,p_1p_2	(4)

(1) Each SKU is located at one and exactly one location.
(2) Maximal S SKU can be located on one shelf.
In this case S is 24.
(3) Only if order k is located at location p_1 and p_2 both can be 1.
(4) If it is true it is 1, else 0.

Appendix H

An example of some sets with their article number and underlying parts.

Article Nr.	Location	Part Nr.	Amount	Old location	New location
05294	0F5104				
		51839	2.00	0D3006	0G4204
		51913	4.00	0D3104	0G4204
05271	0F5104				
		51826	1.00	0D3704	0G4204
		51726	1.00	0D3705	0G4204
05268	0F5104				
		51732	1.00	0H3207	0G4200
		51734	1.00	0C182B	0G4201
		51828	1.00	0D3407	0G4201
		51829	1.00	0D3200	0G4202
		78020	1.00	0D3504	0G4202
		78022	1.00	0D3706	0G4202
		51733	1.00	0D3803	0G4200
		78021	1.00	0D3505	0G4201
05476	0F5104				
		70179	1.00	0E3302	0G4203
		78171	1.00	0D3605	0G4203
05313	0F5104				
		51848	2.00	0D4303	0G4006
		51850	2.00	0D3007	0G4001
		51852	2.00	0G1602	0G4005
		51853	2.00	0D3006	0G3806
		51893	2.00	0D2801	0G4005
		52046	2.00	0D3802	0G4001
		78012	2.00	0D3705	0G4005
		78104	2.00	0D2905	0G4006
		78112	2.00	0D2905	0G4005
		78121	2.00	0D2801	0G4006
		6000761	2.00	0D3207	0G3806
05313	0F5104				
		51848	2.00	0D4303	0G4006
		51850	2.00	0D3007	0G4001
		51852	2.00	0G1602	0G4005
		51853	2.00	0D3006	0G3806
		51893	2.00	0D2801	0G4005
		52046	2.00	0D3802	0G4001
		78012	2.00	0D3705	0G4005
		78104	2.00	0D2905	0G4006
		78112	2.00	0D2905	0G4005
		78121	2.00	0D2801	0G4006
		6000761	2.00	0D3207	0G3806

Appendix I

To come up with possible options, a sales person from Hänel has visited Trioliet. After this visit he has sent two possible efficient and compact storage systems: a VLM and a vertical carousel. The specifics of these options are explained below:

A possible VLM is the 3260-825, with the following characteristics:

- Size: 3,605 x 2,810 x 8,028 mm.
- Number of plateaus: 55
- Useful space per plateau (WxD): 3,260 x 825 mm.
- Average filling height: 200 mm
- Capacity: 148 m2 / 33 m3
- Needed floor space: 10 m2
- Capacity for bins (WxDxH) 290 x 400 x 200 mm: around 1,210 bins
- Bearing capacity per plateau: 180 kg
- Bearing capacity per bin: 8.2 kg
- Pick speed: ca 120 units per hour
- Price: € 50,000.-

Another option is a vertical carousel, the R936:

- Size 3.420 x 1.615 x 8,020 mm.
- Number of plateaus : 37
- Useful space per plateau (WxDxH): 2.915 x 630 x 343 mm.
- Number of intermediate floor: 37
- Total number of floors : 74
- Capacity 136 m2 / 23 m3
- Needed floor space: 5,5 m2
- Capacity for Bins (WxDxH) 234 x 600 x 140 mm: 888 bins or
- Capacity for Bins (WxDxH) 234 x 600 x 90 mm: 1,332 bins
- Bearing capacity per plateau: 117 kg
- Bearing capacity per bin : 47 kg (per bins, 234 x 600 x 140 mm: 4 kg)
- Pick speed: ca 120-200 units per hour
- Price: € 44,000.-

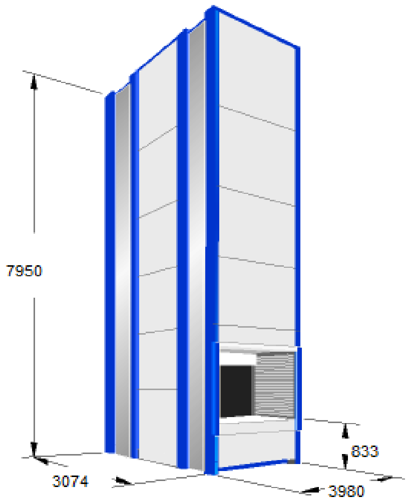
Appendix J

In collaboration with Kardex Remstar an implementation plan for three vertical lift modules is created. In this appendix this implementation is explained.

There is chosen for an implementation plan with three vertical lift modules with 71 plateaus in each VLM. The maximum weight per plateau is 450 kilogram. Information about floor load is depicted in the figure.

Total unit weight:	41224	[kg]
Unit dead weight:	3665	[kg]
Load gross:	37559	[kg]
Load net:	31950	[kg]
Total load gross:	2x35000	[kg]

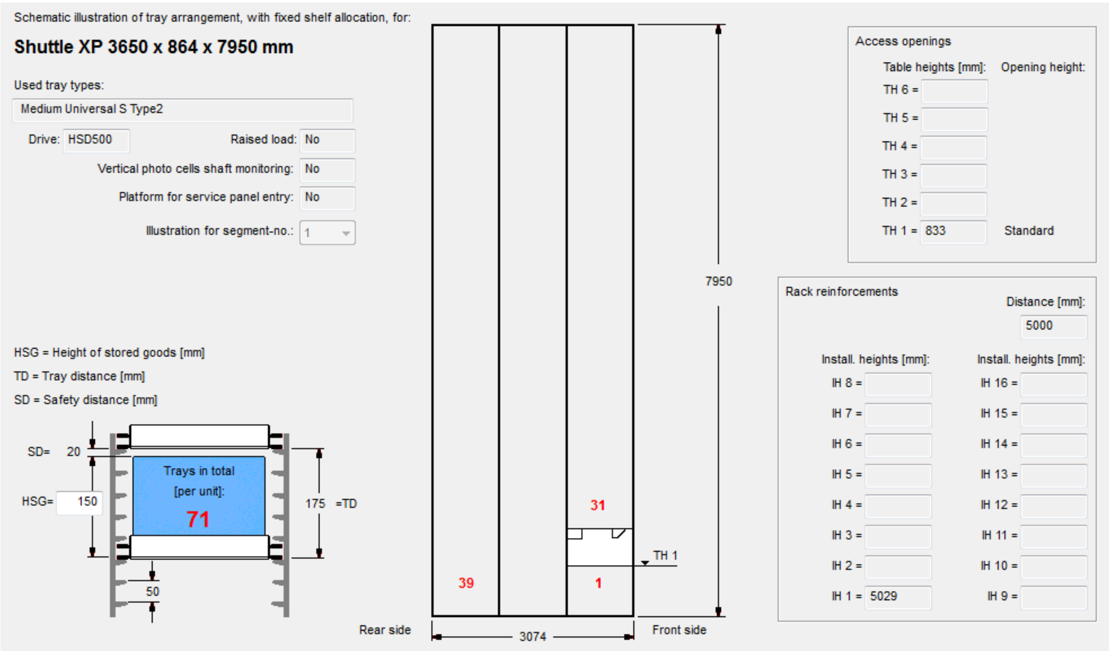
This three VLMs together have (3x71=) 213 plateaus. The total capacity for these plateaus together is 672 square meters. In total between 5000-6000 parts can fit in these VLMs.



At this moment 472 square meter floor space is occupied with the shelving. These three VLMs will occupy 36 square meters. There is some extra space needed for the picking table or picking carts.

The VLM that is advised is the ‘Shuttle HSD500’. The dimensions are 3,650 x 864 x 7,950 (WxDxH) millimeters. The cost of these three VLMs together is € 165,000.-.

An extra option is the software from Kardex Remstar, ‘Power Pick Global’. This is a software system to optimize the VLMs. ‘Power Pick Global’ maximizes storage density within a storage unit and offers complete inventory control and traceability. It provides storage and retrieval of items and prevents out-of-stock inventory. Functionality can be further enhances through a wide variety of modules. The price of this software is € 25,000.-.



Appendix K

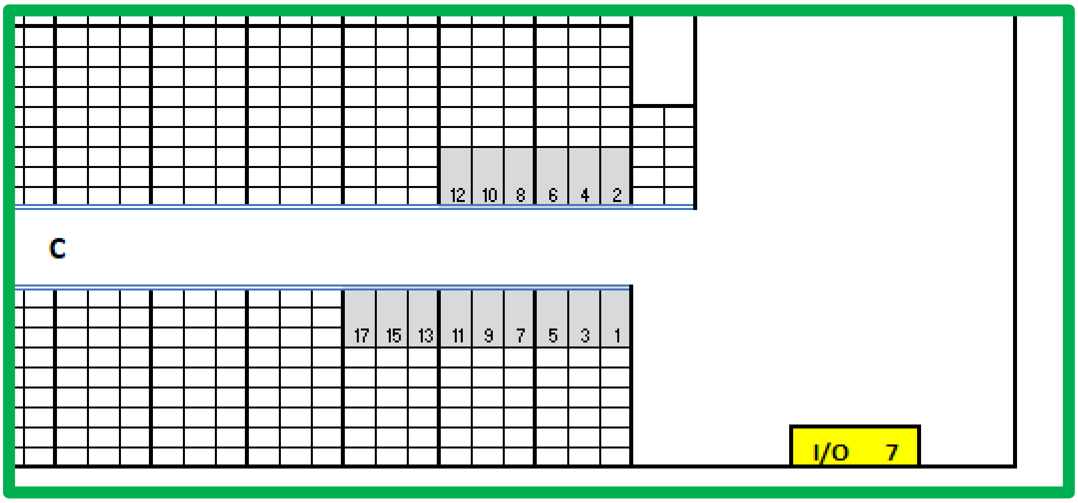
New and old distances.

- The total distance per part picked is calculated.
- The total distance for old and new situation are calculated.
- The average travel distance in old and new situation are calculated.
- --

The first pallet rack is 1 meter round trip from the I/O point.

The second pallet rack (across the first) is 1 meter round trip from the I/O point.

See both green figures for the calculation. 1R, 2R and 3R are in the first pallet rack, so 1 meter.



Location	Distance
1R	1
2R	1
3R	1
4R	2
5R	2
6R	2
7R	3
8R	3
9R	3
10R	4
11R	4
12R	4
13R	5
14R	5
15R	5
16R	6
17R	6
18R	6
19R	7
20R	7
21R	7
22R	8
23R	8
24R	8
25R	9
26R	9
27R	9
28R	10
29R	10
30R	10
31R	11

Location	Picks	Distance	total
1R	16292	1	16292
2R	6106	1	6106
3R	5597	1	5597
4R	5344	2	10688
5R	5271	2	10542
6R	3455	2	6910
7R	3163	3	9489
8R	2933	3	8799
9R	2702	3	8106
10R	2604	4	10416
11R	2507	4	10028
12R	2434	4	9736
13R	2422	5	12110
14R	1964	5	9820
15R	1905	5	9525
16R	1214	6	7284
17R	788	6	4728
18R	734	6	4404
19R	694	7	4858

The amount of picks is multiplied with the distance. So for example 7R:

- 3136 picks are done from that location
- The distance is 3 meters.
- 3136 x 3 = 9489 meters in total
- See red figure for example.

Total

Old situation is:	5,790,295 meter	=	40.8 meter per part
New situation is:	4,172,419 meter	=	29.4 meter per part

Difference 27.9 %